40p

GEMSTONES

1. Absorption-spectrum (almandine). 2. Almandine. 3. Almandine (carbuncle). 4. Rhodolite. 5. Topaz. 6. Topaz. 7. Zircon. 8. Pyrope. 9. Gahnospinel. 10. Grossular. 11. Zircon. 12. Zircon. 13. Demantoid. 14. Star-stone (ruby). 15. Zircon. 16. Absorption-spectrum (zircon).

I. GEMSTONES AND ABSORPTION-SPECTRA

GEMSTONES

BY

G. F. HERBERT SMITH
C.B.E., D.Sc., M.A.
Late President of the Gemmological Association of Great Britain

REVISED BY

F. C. PHILLIPS, M.A.
Reader in Petrology, University of Bristol

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PREFACE TO THE THIRTEENTH EDITION

The first edition of this book was published in 1912. Little change was made in successive editions until twenty-eight years later, when the text was almost completely re-written for the ninth edition in 1940. Again in 1949, when the text was reset for the tenth edition, opportunity was taken to widen the scope further and in places to deepen the discussion. This version continued to the twelfth edition, 1952, with only minor corrections and additions. Dr Herbert Smith died in 1953; in 1955 I accepted an invitation to prepare a further revised edition.

In planning the revision I have had constantly in mind the needs of those for whom the book was originally designed. Continued expansion in scope, together with increasing costs of production, were tending to raise the price beyond the reach of many students, so that some reduction in size seemed imperative. The chapter on crystal form and structure, expanded in the tenth edition to constitute almost a treatise on crystal morphology, has been rewritten more succinctly to cover only those aspects of morphology and structure strictly relevant to the study of gem materials. Some reduction in length of the chapters on optical properties has been achieved by omission of the analytical treatment of the indicatrix, a simplified account sufficing to explain the behaviour of shadow edges on the refractometer.

In previous editions the use of the polarizing microscope had been mentioned only incidentally; in view of the importance of this instrument in the examination of gems at the present time it seemed essential to introduce a chapter describing its use systematically. The tenth edition still retained in chapter XVI, for want of more realistic figures, prices that had prevailed in 1939. I have thought it best to omit almost all references to monetary values, and have added instead in this chapter a short account of the formation of gemstones.

The descriptive sections are largely unchanged, except for a few additions and for bringing up to date in detail. Early editions of the book recognized in their arrangement a distinction between *precious* and *semi-precious* stones. In the tenth edition it was considered no longer desirable to speak of semi-precious stones, and the grouping of the previous editions was abandoned. I have thought it advisable to make further changes here. Under each of the major divisions of *Gemstones* and *Ornamental Stones* I have described the more important representatives in individual chapters, and have then grouped all the remaining less important stones together in alphabetical order. It is hoped that this arrangement, aided also by the re-introduction of figures in bold type in the index to denote main descriptions, will contribute to easier reference.

Some reduction in length has been effected in the final section on organic products; this has unfortunately called for the omission of the striking drawings by Lieut.-Col. W. P. C. Tenison which first appeared in the tenth edition. Certain other plates have been replaced by new illustrations. The bibliography, first added in the ninth edition, has been brought up to date and re-arranged in an attempt to add to its usefulness.

It is a pleasure to acknowledge the help which I have received during the work of revision. I am greatly indebted to Mr G. F. Andrews for assistance and advice freely given throughout; he has been tireless in tracing sources of information, supplying material for illustrations, checking references and reading proofs. Mr B. W. Anderson has read and advised on parts of the revised text, and in particular has brought up to date the data on absorption-spectra in chapter VII; he has also kindly supplied originals for two new illustrations. Mr J. R. H. Chisholm has given invaluable help by reading the whole of the proofs. Dr G. F. Claringbull has checked statements concerning specimens in the Mineral Collection of the British Museum (Natural History). Dr L. R. Cox has steered me through the pitfalls of zoological nomenclature in chapter XXXIX. Miss J. M. Sweet has supplied corrections and additions to the accounts of famous diamonds. The revision owes much to painstaking and detailed criticism by Mr R. Webster, whose wide experience has helped me to remove obscurities and errors and to improve the text at many points. To Dr E. J. Gübelin and the Council of the Gemmological Association of Great Britain I am indebted for permission to reproduce a number of photographs of inclusions in gems; the illustration of a gemmological microscope was kindly supplied by Messrs Rayner & Keeler, and that of Verneuil chalumeaux in operation by Salford Electrical Instruments Ltd.

In the preface to the first edition the author expressed the hope that those engaged in the jewellery trade would find the book helpful in their daily work, and that readers generally might learn to appreciate the variety of beautiful minerals suitable as gems. This hope was realized from the beginning; the present changes, like those effected by the author in 1940, have been designed to make the book even more useful, interesting, and profitable than it has been in the past.

F. C. PHILLIPS

July 1957

PREFACE TO THE 1962 REPRINT

Minor changes have been made in the present edition, correcting misstatements or bringing the text up to date. I am indebted to a number of individuals who, in reviews or in personal communications, have suggested improvements of this kind. Mr J. R. H. Chisholm, amongst many helpful comments, drew attention to the fact that the figures of the Koh-i-nur and Pitt (Regent) diamonds used in previous editions were inaccurate. Dr G. F. Claringbull, Keeper of Minerals at the British Museum (Natural History), kindly arranged for Mr C. R. Hill to make revised drawings of accurate models from which new blocks have been prepared.

F. C. PHILLIPS

June 1962

EXTRACT FROM THE PREFACE TO THE NINTH EDITION

The general plan of the book remains now much the same as before, but it has been divided on more logical lines.

A new chapter on Bible Stones has been added; it is founded on the scholarly article prepared by the late Sir Lazarus Fletcher, F.R.S., for the guide-book which was compiled for the exhibit set out at the British Museum (Natural History) in 1911, the tercentenary of the Authorized Version.

For the present edition an entirely new set of drawings in colour have been made by Miss Helen Wilson. As reproduced, they represent as faithfully as possible both the size and the appearance of the original specimens. With only two exceptions—the diamond and the blue sapphire—they were taken from the unrivalled collection of gemstones in the Mineral Collection of the British Museum (Natural History). In many instances I thought that natural crystals would be of more interest to readers than cut stones.

In the preparation of the general text I have freely consulted many books on precious stones, pearls, and mineralogy, including in particular Professor Dr Schlossmacher's edition of Professor Dr Max Bauer's *Edelsteinkunde*, Dr W. F. Eppler's edition of Dr Alfred Eppler's *Edelsteine und Schmucksteine*, *The Book of the Pearl* by Dr G. F. Kunz and Dr C. H. Stevenson, and the hand-book *Gemstones* issued by the Imperial Institute. For the correct etymology of the names of gemstones and other minerals I have relied upon the *New English Dictionary*, commonly known as the *Oxford Dictionary*.

It is pleasant to acknowledge the immense amount of help which I have received, whereby my task has been considerably lightened. Her Majesty the Queen was graciously pleased to show me the charming necklace which contains as its centre-piece the historic Timur Ruby. To Mr B. W. Anderson, and Mr C. J. Payne, of the Laboratory of the Diamond, Pearl, and Precious Stone Trade Section of the London Chamber of Commerce, I owe an especial debt of gratitude. They have freely and generously placed at my disposal their extensive experience of gemstones and pearls, and thus enabled me to make a thorough revision of the data given in the book.

Dr Max H. Hey supplied me with particulars about chemical and other information. Dr G. F. Claringbull, my co-examiner in gemmology, has helped me in connexion with the illustrations of absorption-spectra and in other ways. Mr A. C. Townsend helped me in tracing various references, and in revising the bibliography in Appendix C; Mr J. J. Mugford supplied me with the list of books on gemstones in the Museum Library, upon which the bibliography has been based. Mr Arthur Tremayne allowed me to reproduce the photographs of the absorption-spectra of zircons, which originally appeared in *The Gemmologist*. Mr E. Trillwood supplied me with various items of information. His Excellency the Soviet Ambassador most kindly procured for me information about the historic jewels in the Diamond Treasury at Moscow. My thanks are due to the firm I. J. Asscher for the illustrations of diamond cutting; to Messrs Rayner & Keeler for the illustration of the Rayner refractometer; to Messrs K. Mikimoto for the photographs of pearl-farming; and to the London Chamber of Commerce for the X-ray photographs of native and cultured pearls.

G. F. H. S.

March 1940

I

INTRODUCTION

Beauty, durability and rarity: such are the three cardinal virtues of a perfect gemstone. Stones lacking any of them cannot aspire to a high place in the ranks of precious stones, although it does not necessarily follow that they are of no use for ornamental purposes. The case of pearl, which, though not properly included among gemstones, being directly produced by living agency, yet holds an honoured place in jewellery, constitutes to some extent an exception, since its incontestable beauty atones for its comparative lack of durability.

That a gemstone should be a delight to the eye is a truism that need not be laboured; for such is its whole *raison d'être*. The members of the Mineral Kingdom that find service in jewellery may be divided into three groups, according as they are transparent, translucent or opaque. Of these, the first, which is by far the largest and the most important, may itself be further sub-divided into two sections: stones which are devoid of colour, and stones which are tinted. Among the former, diamond reigns supreme, since it alone possesses that marvellous fire, oscillating with every movement from heavenly blue to glowing red, which is so highly esteemed and so much sought after. Other stones, such as fired zircon, white sapphire, white topaz and rock-crystal, may dazzle with brilliancy of light reflected from the surface or emitted from the interior, but none of them, like diamond, glows with mysterious gleams. It taxes all the skill of the lapidary to ensure that the disposition of the facets be such as to reveal the full splendour of the stone. A coloured stone, on the other hand, depends for its attractiveness more upon its intrinsic hue than upon the manner of its cutting. The tint must not be too light or too dark in shade: a stone that has barely any colour has little interest, and one which is too dark appears almost opaque and black. The lapidary can to some extent remedy these defects by cutting the former deep and the latter shallow. In certain curious stones—for instance tourmaline—the transparency, and in others—such as ruby, sapphire and one of the more recent additions to the gem world, kunzite—the colour, varies considerably in different directions. The colours that are most admired—the fiery red of ruby, the royal blue of sapphire, the verdant green of emerald and the golden yellow of topaz—are pure tints, and the absorption-spectra corresponding to them are on the whole continuous and often restricted. They therefore retain the purity of their colour even in artificial light, though certain sapphires transmit a relatively larger amount of red, and consequently turn purple at night. Of the small group of translucent stones which pass light, but are not clear enough to be seen through, the most important is opal. It and certain others of the group owe their merit to the same optical effect as that characterizing soap-bubbles, tarnished steel and so forth, and not to any intrinsic coloration. Another set of stones—moonstone and the star-stones—reflect light from the interior more or less regularly, but not in such a way as to produce a play of colour. The last group, which comprises opaque stones, has few representatives among ordinary gemstones, the principal ones being turquoise, lapis-lazuli and jade. In this case light is scattered and reflected from layers immediately contiguous to the surface, and the colour is due to the resulting absorption. The apparent darkness of a deep-coloured stone follows from a different cause: the light passing into the stone is wholly absorbed within it, and, since none is emitted, the stone appears black. The claims of turquoise are maintained by the blue variety; there is little demand for stones of a greenish tinge.

It is obviously desirable that any stones used in jewellery should be able to resist the mechanical and chemical actions of everyday life. No one is anxious to replace jewels every few years, and the most valuable stones are expected to endure for all time. The mechanical abrasion is caused by the minute grains of sand that are contained in ordinary dust, and gemstones should be at least as hard as they—a condition fulfilled by all the principal species with the exception of opal, turquoise, peridot and demantoid. All four, however, are only slightly softer than sand. It may be noted that the softness of paste stones, apart from any objections that may be felt to the use of imitations, renders them unsuitable for jewellery purposes. Plastics, too, are soft, much more so even than paste and other glass imitations, and cannot therefore be expected to stand up to hard usage; nevertheless, certain kinds possess ideal limpidity and can assume delightful tints, and are consequently likely to commend themselves to those on the look out for pleasing, yet cheap ornaments, and indifferent to their poor wearing qualities. The only gemstones that are likely to be chemically affected in the course of wear are those which are in the slightest degree porous. It is hazardous to immerse turquoises in liquids, even in water, lest the bluish-green colour be oxidized to the despised yellowish hue. The risk of damage to opals, moonstones and star-stones by the penetration of dirt or grease into the interior of the stones is less, but is not wholly negligible. Similar remarks apply with even greater force to pearls. Their charm, which is due to a peculiar surface-play of light, might be destroyed by contamination with grease, ink or similar matter; they are, moreover, soft.

It cannot be gainsaid that mankind prefers the rare to the beautiful, and what is within reach of all is lightly esteemed. It is for this reason that for many years garnet and moonstone lay under a cloud. Purchasers could readily be found for a 'Cape-ruby' or an 'olivine', but not for a garnet; garnets are so common, was the usual remark. Nevertheless, the stones mentioned are really garnets. If science succeeded in manufacturing diamonds at a cost of shillings instead of the pounds that are now asked for Nature's products—not that such a prospect is at all probable—we might expect them to vanish entirely from fashionable jewellery.

A careful study of the showcases of the most extensive jewellery establishment brings to light the fact that, despite the apparent profusion, the number of different species represented is restricted. Diamond, ruby, emerald, sapphire, pearl and opal are all that are ordinarily asked for; yet, as later pages will show, there are many others worthy of consideration. For the first five of the species mentioned above, the demand in normal times is relatively steady, and varies absolutely only with the purchasing power of the world; but a lesser stone may suddenly spring into prominence owing to the caprice of fashion or the preference of some great lady or leader of fashion. Several years ago, for instance, violet was the favourite colour for ladies' dresses, and consequently amethysts were much worn to match, but with the change of fashion they speedily sank to their former obscurity. Another stone may perhaps figure at some royal wedding, the sapphire in 1935 being a case in point; for a brief while it becomes the vogue, but before long it returns to its normal position.

Except that diamond, ruby, emerald and sapphire, and, we should add, pearl, may indisputably be considered to occupy the first rank, it is impossible to place the gemstones in any strict order; but in a discussion of their scientific properties the varieties of a mineral species must be grouped together to avoid needless repetition, and in this book aquamarine, though so much less valuable than emerald, is therefore placed with it under beryl. Every generation sees some change. The value of a stone is after all merely what it will fetch in the open market, and its artistic merits may be a matter of opinion. The familiar aphorism, *de gustibus non disputandum*, is a warning not to enlarge upon this point.

Recent generations differ markedly from their predecessors in their attitude towards imitation jewellery and especially imitation pearls, and it is by no means uncommon to see wearers, who apparently would claim some pretensions to taste, adorned with ear-rings and necklaces which are palpably false. Although it is difficult to gauge anything so tenuous and incalculable as feminine whim, the cause of this changed attitude may perhaps be traced to the spread of the cheap store and the influence of the films. Trinkets, which for a time at least are attractive to the eye, can now be acquired at low figures, and it may appear but ordinary prudence to prefer such articles to relatively costly stones, if in the circumstances of wear they are liable to be lost or damaged. The general use of screw-fittings for ear-rings instead of holes passing through the lobes is a contributing factor. The threads of such small stems cannot be very durable, and sooner or later, unless very exceptional care be taken, the screw gives sufficiently for one ear-ring to fall off without the cognizance of the wearer until too late to retrieve it. Necklaces, too, worn in the daytime out of doors under a wrap may easily disappear, owing to the failure of the clasp to catch or possibly to hold, without the wearer realizing the loss. For similar reasons paste and plastic imitations are used for shoe-buckles and other articles which may be easily lost or damaged.

Descriptions of stones, however detailed and lucid, and illustrations, however good, cannot wholly replace visual experience, and readers are advised to study the cut stones exhibited in museums, especially in the large national institutions in London. The Mineral Collection in the British Museum (Natural History) contains a large and varied series of cut stones, which are mostly arranged in the General Collection so that the worked specimens may conveniently be compared with the natural material. Two unusually interesting collections have, however, been kept apart. The one was formed by Sir Arthur H. Church, and after his death was presented by his widow in 1915; it is particularly rich in zircons. The other was bequeathed in 1934 by Mr Thomas B. Clarke-Thornhill; it includes a variegated suite of coloured diamonds, many large stones and a vividly dichroic alexandrite. A striking feature of the Museum of Practical Geology is the extensive series of worked stones exhibited on the floor of the hall. The Victoria and Albert Museum contains a choice collection of cut stones, which was bequeathed in 1869 by the Rev. Chauncy Hare Townsend. It was originally arranged in the Museum by Sir Arthur Church, who presented various beautiful stones to fill gaps in the collection. Included in it are some fifty specimens which were formerly in the Henry Philip Hope collection of pearls and precious stones. Representative, though smaller, collections are displayed in many City Museums and other institutions in provincial centres, as at Birmingham, Edinburgh and Glasgow.

Part I

PHYSICAL CHARACTERS

II

CRYSTAL FORM AND STRUCTURE

A. CRYSTAL AND GLASS

With the single exception of opal, the whole of the principal mineral species used in jewellery are distinguished from glass and similar substances by the fundamental distinction that they are crystallized matter, and the atoms composing them are regularly arranged throughout the structure.

The words, crystal and glass, are employed in science in senses differing considerably from those in popular use. The former of them is derived from the Greek word, *κρύος*, meaning ice, and was at one time used in that sense. For instance, the old fourteenth-century rendering of Psalm cxlvii. 17, which appears in the Authorized Version as 'He casteth forth his ice like morsels', ran: 'He sendis his kristall as morcels'. It was also applied to the beautiful, lustrous quartz found among the eternal snows of the Alps, since, on account of their limpidity, these stones were supposed, as Pliny[1] tells us, to consist of water congealed by the extreme cold of those regions; such at the present day is the ordinary meaning of the word. But, when early investigators discovered that a salt solution on evaporation left behind groups of slender, glistening prisms, each very similar to the rest, they naturally—though, as we now know, wrongly—regarded them as representing yet another form of congealed water, and applied the same word to such substances. Subsequent research has shown that these salts, as well as mineral

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[1] 'It is a diametrically opposite cause to this that produces crystal, a substance which assumes a concrete form from excessive congelation. At all events, crystal is only to be found in places where the winter snow freezes with the greatest intensity; and it is from the certainty that it is a kind of ice, that it has received the name which it bears in Greek.' (Contraria huic causa crystallum facit, gelu vehementiore concreto. Non aliubi certe reperitur, quam ubi maxime hibernae nives rigent: glaciemque esse certumest: unde et nomen Graeci dedere.) Caii Plinii Secundi Historiae Naturalis Libri XXXVII, book 37, ch. 2. Caius Plinius Secundus, Pliny the Elder, was born in A.D. 23 and perished in A.D. 79 while investigating the great eruption of Vesuvius, which overwhelmed Herculaneum and Pompeii. Secundus was part of his family name. His great work on natural history was issued in A.D. 77.

substances occurring in nature, often with flat faces, have in common the fundamental property of regularity of arrangement of the constituent atoms, and science therefore defines the word, crystal, as a substance in which the structure is uniform throughout, and all the similar atoms composing it are arranged with regard to the structure in a similar way.

The other word, glass, is yet more familiar; it denotes the transparent, lustrous, hard and brittle substance produced by the fusion of sand with soda or potash, or both, which fills our windows and serves a variety of useful purposes. Research has shown that glass, although apparently so uniform in character, has in reality no regularity of atomic arrangement. It is, in fact, a kind of three-dimensional mosaic of atoms, huddled together anyhow, but so irregular is its irregularity that it simulates perfect regularity. Science uses the word, glass, in this widened meaning. Two substances may, as a matter of fact, have the same chemical composition, and the one be a crystal and the other a glass. For example, quartz, if heated to a high temperature, may be fused and converted into a glass (p. 373). The difference in the two types of structure may be illustrated by a comparison between a battalion of soldiers drawn up on parade and an ordinary crowd of people.

Various glasses occur in nature (p. 421). The longest known of them is obsidian, which is a glass formed by the rapid cooling of lava ejected by an active volcano. Tektite is the general name given to the mysterious pieces of greenish glass found in different parts of the world and known as moldavite, australite or billitonite, according to the locality. Since they are found far from volcanic regions, tektites must differ from obsidians in their origin. Where they have sprung from is still problematical; it has been suggested that they are meteoric in origin, that is, they have reached us from outer space, but they differ from any known meteorite in composition and physical characters, and have never been seen to fall. The origin of the silica-glass that has been discovered in good-sized lumps in the Libyan Desert in North Africa is still uncertain. The silica-glass of much greater irregularity of shape that has been found near some meteor craters is the result of the fusion of sand by the heat generated by the fall of a vast meteorite. It may be concluded that both tektites and the silica-glass in the Libyan Desert have been formed by intense heat, but the source of the heat remains uncertain.

A class of mineral, which is neither crystal nor glass, is represented by opal. When hot silica-bearing water in the earth approached the surface, owing to the resulting rapid cooling and evaporation it deposited the silica in a gelatinous form, containing a variable amount of water, which is known as opal. Subsequently, owing to crystallization, it is often transformed to chalcedony.

B. CRYSTAL MORPHOLOGY

Natural crystals, with few exceptions, are bounded by plane crystal faces. In small crystals these faces are often optically flat and afford sharp reflected images of objects (such as the bars of a window); larger crystals often have less perfect faces, and reflections from them may be somewhat diffuse. The plane faces are an outward expression of the regularity of the internal atomic arrangement which characterizes the crystalline state. The study of the development and disposition of these natural faces is the branch of crystallography termed crystal morphology. An understanding of the morphology of gem minerals may often be of service in distinguishing stones when in the rough state; and it is also of great importance to the lapidary who wishes to cut a stone to the best advantage.

I CRYSTAL SYMMETRY

In a well-shaped crystal, such as of garnet (fig. 1) or of zircon (fig. 2), it will be observed that sets of similar faces exist. The disposition of these similar faces is an expression of the *symmetry* of the crystal (ultimately of the symmetry of its internal atomic structure). All crystals of the same substance show the same degree of symmetry, but crystals of different substances may show very different degrees of symmetry. Thus garnet has a very high degree of symmetry, that of zircon is somewhat lower, whilst orthoclase (fig. 3) and axinite (fig. 4) afford examples of still lower symmetry. The elements of symmetry possessed by a crystal may be of three types. In the examples so far illustrated each crystal face has a similar face parallel to it on the opposite side of the

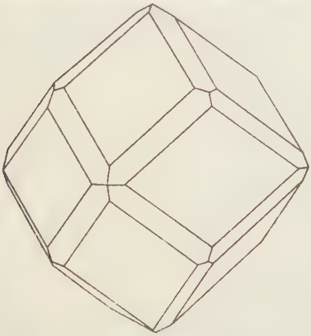

FIG. 1.—A crystal of garnet.

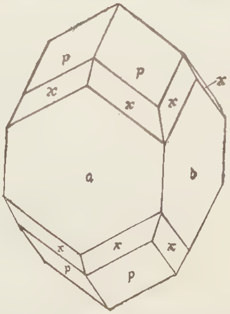

FIG. 2.—A crystal of zircon.

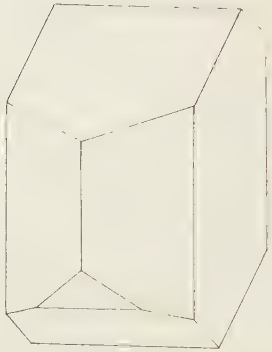

FIG. 3.—A crystal of orthoclase.

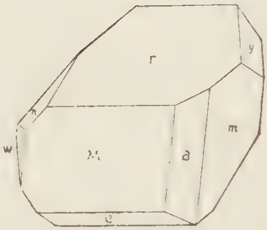

FIG. 4.—A crystal of axinite.

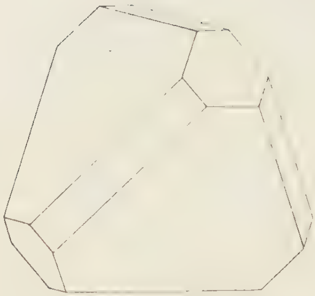

FIG. 5.—A crystal of blende.

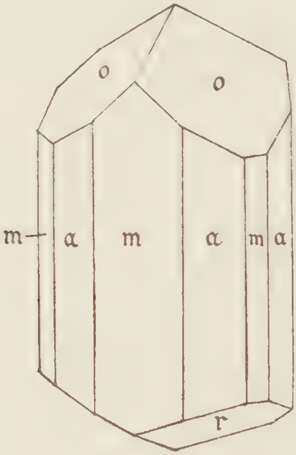

FIG. 6.—A crystal of tourmaline.

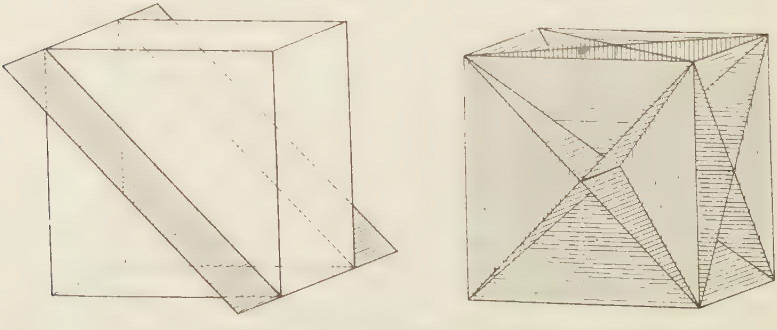

FIG. 7.—Diagonal planes of symmetry in a cube.

crystal, and such crystals are said to show a *centre* of symmetry. Some substances, however, grow characteristically with certain faces, at least, which have no parallel similar face—they lack a centre of symmetry. Blende (fig. 5) and tourmaline (fig. 6) afford examples.

A second type of symmetry element is the *plane* of symmetry. Along such a plane the crystal may be imagined divided into two precisely similar portions, but there is an important restriction in the crystallographic concept in comparison with that of a purely geometrical symmetry plane. Not only must the two portions be identical, but they must be situated as mirror reflections one of the other in the plane. Thus, whilst there are diagonal planes of symmetry at right angles to each square face of a simple cube (fig. 7), there are no planes of crystallographic symmetry in the diagonal positions in a rectangular parallelepiped (fig. 8). The number of planes of symmetry displayed may vary widely from one substance to another. A simple cube shows nine planes of symmetry, three of one kind parallel to the faces of the cube (fig. 9) and the six diagonal planes (fig. 7). Orthoclase shows a single plane of symmetry (fig. 10), whilst quartz (fig. 11) and axinite (fig. 4) show none.

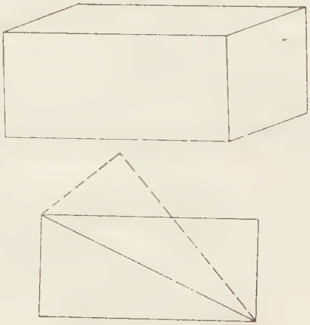

FIG. 8.—A diagonal plane in a rectangular parallelepiped is not a crystallographic plane of symmetry.

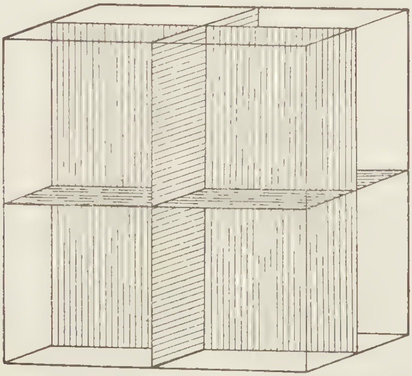

FIG. 9.—Three principal planes of symmetry in a cube.

The third type of crystallographic symmetry element is the *axis* of symmetry. When a crystal is rotated about such an axis it assumes a congruent position n times during a complete revolution, where n is the *degree* of the axis. Axes of symmetry of four different degrees are encountered in crystals:

$n = 2$ giving congruence every 180° = digonal (or diad) axis.
3 ,, ,, ,, 120° = trigonal (or triad) axis.
4 ,, ,, ,, 90° = tetragonal (or tetrad) axis.
6 ,, ,, ,, 60° = hexagonal (or hexad) axis.

As with planes of symmetry, different substances may show widely varying assemblages of axes of symmetry. Whilst a simple cube has three tetragonal axes, four trigonal axes and six digonal axes, orthoclase, with its single plane of symmetry, has also only a single digonal axis; kyanite has no axis of symmetry at all. The different assemblages of axes of symmetry afford a basis for the classification of crystals, but before turning to this some other aspects of crystal morphology demand attention.

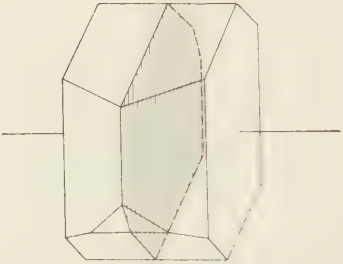

FIG. 10.—Single plane of symmetry in orthoclase.

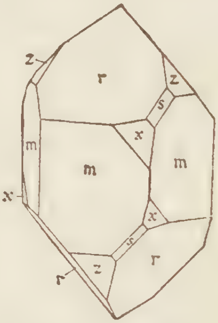

FIG. 11.—A crystal of quartz.

2 FORM AND HABIT

Whilst all crystals of the same substance must display the same assemblage of symmetry elements this does not, of course, imply that all the crystals will have the same general appearance. Garnet, which has the same symmetry as that of the simple cube (13 axes, 9 planes and a centre), is often found in crystals of the shape illustrated in fig. 12, the twelve-faced *rhombic dodecahedron*. It is found also as a twenty-four-faced solid (fig. 13), the *icositetrahedron* (or trapezohedron), and these two shapes are described as different *forms*. Still other crystals of garnet may have the appearance of fig. 14 or fig. 15, and it may not be easy at first to appreciate that both these thirty-six-faced shapes are combinations of the forms of fig. 12 and fig. 13. Such variations in shape between different crystals of the same substance are variations of *habit*, which is determined by the relative development of different forms. The crystals of both fig. 12 and fig. 15 are of dodecahedral habit, whilst those of fig. 13 and fig. 14 are of icositetrahedral habit.

A characteristic feature of many of the crystals so far illustrated is a tendency to the development of sets of faces which intersect in series of parallel edges; such a set of faces is termed a *zone*. Some substances—beryl (fig. 16) and epidote (fig. 17), for example—tend to grow in crystals considerably elongated parallel to the edges of one prominent zone and are said to show a *prismatic* habit, which passes to an *acicular* (or needle-shaped) habit with extreme elongation (as in the rutile needles in rutilated quartz). Marked flattening parallel to one pair of faces produces a *tabular* habit, as in ruby (fig. 18), or *platy* habit, as in some crystals of haematite.

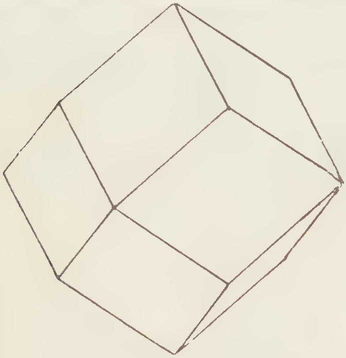

FIG. 12.—The rhombic dodecahedron.

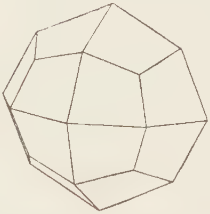

FIG. 13.—An icositetrahedron.

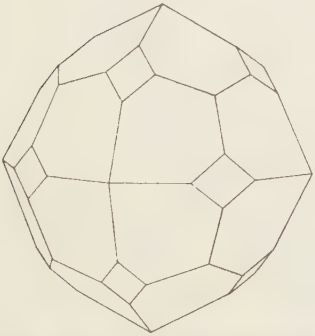

FIG. 14.—A crystal of garnet showing two forms.

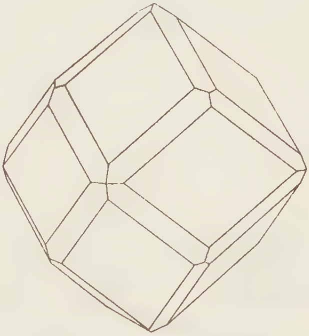

FIG. 15.—A crystal of garnet differing in habit from that of fig. 14.

A form may be defined precisely as 'the assemblage of faces required by the symmetry when one face is given'. Suppose, for example, that a substance has a structure which results in a hexagonal axis of symmetry normal to a plane of symmetry (the symmetry displayed by apatite). A face inclined to both axis and plane will be repeated six times around the axis, and these six faces will be reflected across the plane, so that the resultant form is a *hexagonal bipyramid* (fig. 19). A face parallel to the hexagonal axis, however, is at right angles to the plane, and so is not repeated by it to produce a new face; the complete form is a *hexagonal prism* (fig. 20), which is open-ended (an *open form*), and which there-

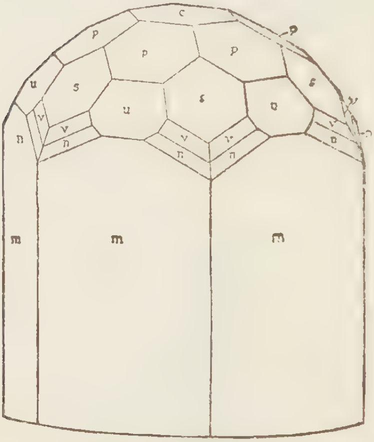

FIG. 16.—A crystal of beryl.

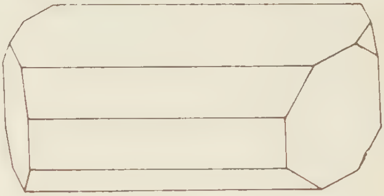

FIG. 17.—A crystal of epidote.

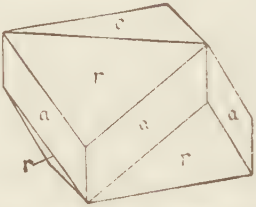

FIG. 18.—A tabular crystal of ruby.

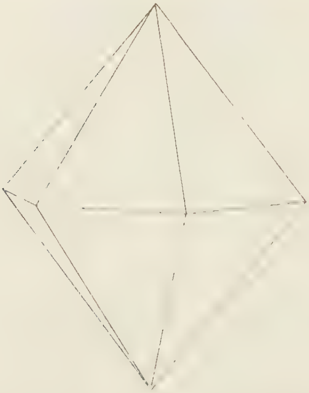

FIG. 19.—A hexagonal bipyramid.

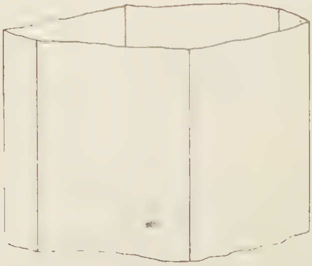

FIG. 20.—A hexagonal prism.

fore cannot exist alone on a crystal. A face at right angles to the hexagonal axis is repeated only by the plane of symmetry to give a parallel face; these two faces constitute another open form, a *pinacoid* (from πίναξ, board). In this group of symmetry these are the only three kinds of form possible, and all crystals of substances belonging to it will be made up of various combinations of them. The three crystals of apatite (fig. 21) show respectively (1) a prismatic habit terminated by small faces of the pinacoid and one hexagonal bipyramid; (2) a tabular habit with pinacoid, an obtuse bipyramid and small faces of a prism; (3) a tabular habit of more complex development with several bipyramids.

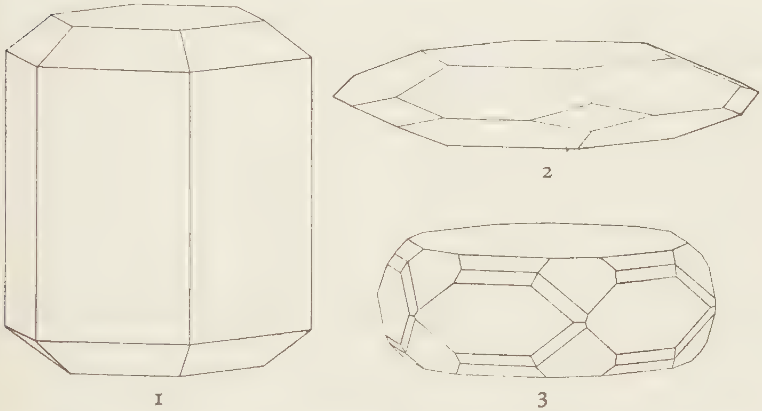

FIG. 21.—Three crystals of apatite: (1) prismatic, (2) and (3) tabular.

In crystal drawings all the faces of one form are sometimes lettered correspondingly (as in some of the annexed figures), but there is unfortunately no generally accepted principle of allocation of particular letters.

One further definition is necessary before turning again to the classification of crystals by symmetry. The hexagonal prism and the pinacoid in the description of apatite arise from faces which have a special relationship to the elements of symmetry, and they are termed *special forms.* They are not uniquely characteristic of this particular group of symmetry, and both would arise, for example, from the operation of a trigonal axis together with a centre of symmetry (the group to which phenakite belongs). The hexagonal bipyramid, however, arises from a face with the most general relationship possible to the elements of symmetry, and is the *general form* for this group of symmetry elements. A different general form will be characteristic of each possible group of symmetry elements (though the general form of one group may appear as a special form in other groups).

3 CRYSTAL SYSTEMS AND CLASSES

Crystals may be grouped into *systems*, which can be most readily defined in terms of the characteristic axes of symmetry present. In Great Britain it is customary to recognize seven such systems:

The *triclinic* (anorthic) system includes all crystals possessing no axes of symmetry.

The *monoclinic* (oblique) system includes all crystals possessing a single digonal axis.

The *orthorhombic* system includes all crystals possessing three mutually perpendicular digonal axes (or the equivalent).

The *trigonal* system includes all crystals possessing a single trigonal axis.

The *hexagonal* system includes all crystals possessing a single hexagonal axis.

The *tetragonal* system includes all crystals possessing a single tetragonal axis.

The *cubic* (regular, isometric) system includes all crystals possessing four trigonal axes. These axes are parallel to the solid diagonals of a cube, being mutually inclined at an angle of 70° 32′ to each other.

(The trigonal system is sometimes grouped as a subdivision—the rhombohedral division—of the hexagonal system, so that only six different systems are then recognized.)

These crystal systems may be further divided into crystal *classes*, according to the precise degree of symmetry present in addition to the characteristic elements of the system. Thirty-two such classes exist, but many of them are of quite minor importance and are scarcely represented among mineral substances. Within each system, by far the greater number of known representatives display the maximum symmetry possible for that system—they belong to the *holosymmetric* class of the system—and it will be necessary to mention here only a few other classes into which important gem materials fall.

i Triclinic (anorthic) System

Holosymmetric (pinacoidal) class

The only symmetry present is a centre. There are no special forms; the general form is a pinacoid, of which at least three representatives must be present on an actual crystal. The plagioclase feldspars, kyanite and rhodonite display this symmetry.

ii Monoclinic (oblique) System

Holosymmetric (prismatic) class

Symmetry: 1 digonal axis, 1 plane (at right angles to the axis), and centre.

Special forms are pinacoids; the general form is a prism. About one-half of the known crystalline substances belong to this class. Among gem materials are orthoclase (fig. 3), spodumene, euclase, sphene, diopside and epidote (fig. 17).

iii Orthorhombic System

Holosymmetric (orthorhombic bipyramidal) class

Symmetry: 3 mutually perpendicular digonal axes, 3 planes (at right angles to the axes), and centre.

Special forms are pinacoids and prisms (often termed *domes* when their edges are horizontal); the general form is a bipyramid. This class is numerically the second in order of importance. Topaz (fig. 22), olivine and chrysoberyl, and the lesser known species andalusite, cordierite, beryllonite, hambergite, danburite, brookite, fibrolite, kornerupine, enstatite and zoisite belong to it.

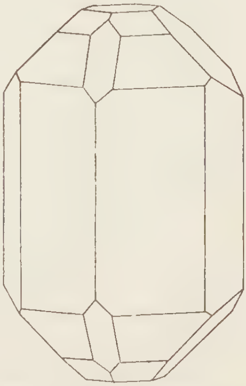

FIG. 22.—A crystal of topaz.

iv Tetragonal System

Holosymmetric (ditetragonal bipyramidal) class

Symmetry: 1 tetragonal axis with 4 digonal axes at right angles to it, 5 planes of symmetry (one at right angles to each of the axes) and centre.

There is a large number of special forms; a generally-situated face is repeated as four pairs of faces around the tetragonal axis, and these are reflected symmetrically below to give a ditetragonal bipyramid. Zircon (fig. 2), cassiterite and idocrase are examples of this class.

Tetragonal bipyramidal class

Symmetry: 1 tetragonal axis, 1 plane (at right angles to the axis) and centre.

Special forms are a pinacoid (developed from a face at right angles to the tetragonal axis) and tetragonal prisms (developed from faces parallel to the axis); the general form is now an eight-faced tetragonal bipyramid —there are no planes of symmetry through the tetragonal axis, as in the previous class, to give a ditetragonal distribution. Scapolite, occasionally cut as a gemstone, belongs to this class.

v Hexagonal System

Holosymmetric (dihexagonal bipyramidal) class

Symmetry: 1 hexagonal axis, 6 digonal axes (at right angles to this axis), 7 planes and centre.

This class is the hexagonal analogue of the holosymmetric class of the tetragonal system. A pinacoid, prisms and hexagonal bipyramids figure in the special forms; the general form has six pairs of faces repeated symmetrically to give a dihexagonal bipyramid. Beryl is a prominent member of this class.

Hexagonal bipyramidal class

Symmetry: 1 hexagonal axis, 1 plane (at right angles to this axis) and centre.

Apatite (fig. 21) has already been described as an example of this class.

vi Trigonal System

Holosymmetric (ditrigonal scalenohedral) class

Symmetry: 1 trigonal axis, 3 digonal axes at right angles to it, 3 planes (at right angles to the digonal axes) and centre.

There is a number of special forms, including rhombohedra (fig. 23). The general form, lacking a horizontal plane of symmetry, is not a bipyramid and is named from the scalene triangular shape of its faces (fig. 24). Corundum, calcite and haematite are examples of this class.

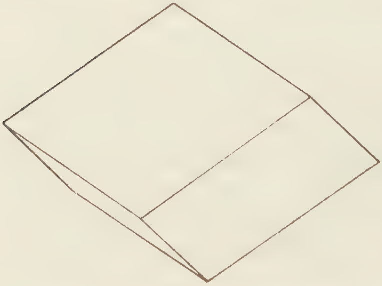

FIG. 23.—A rhombohedron.

Ditrigonal pyramidal class

Symmetry: 1 trigonal axis and 3 planes intersecting in it.

The special forms include both trigonal and hexagonal prisms, so that crystals may have an equilateral triangular cross-section. There is no centre of symmetry and the two ends of crystals with this symmetry differ in character. Tourmaline (fig. 6) is the most conspicuous gemstone in this class.

Trigonal trapezohedral class

Symmetry: 1 trigonal axis, 3 digonal axes at right angles to it.

There are no planes of symmetry, and crystals showing general forms can exist in right- and left-handed modifications which are enantiomorphous—they are true mirror-images and not superposable. Quartz (fig. 11) is a member of this class; it displays well the striking phenomenon of rotatory or circular polarization, first discovered by Arago, which can be directly correlated with a structure lacking planes of symmetry (p. 124).

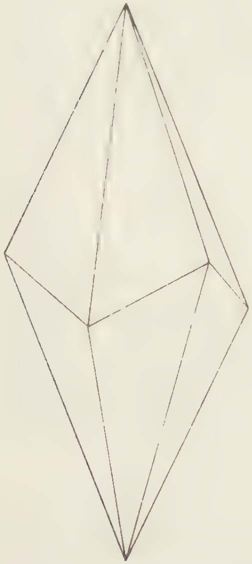

Fig. 24.—A scalenohedron.

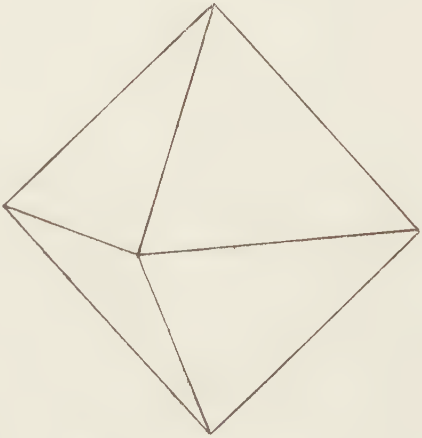

Fig. 25.—The octahedron.

Ditrigonal bipyramidal class

Symmetry: 1 trigonal axis, 3 digonal axes at right angles to it, 3 planes each containing the trigonal axis and one of the digonal axes, and 1 plane at right angles to the trigonal axis.

The sole representative of this class among minerals is the rare gem benitoite. Though the morphology is trigonal, this class is now assigned to the hexagonal system for structural reasons.

Rhombohedral class

Symmetry: 1 trigonal axis and centre.

Special forms are a pinacoid and hexagonal prisms; the general form is a rhombohedron. Phenakite, dioptase and willemite belong here.

vii Cubic (regular, isometric) System

Holosymmetric (hexoctahedral) class

Symmetry: 3 tetragonal axes, 4 trigonal axes, 6 digonal axes, 3 planes (at right angles to the tetragonal axes) and 6 other planes (at right angles to the digonal axes) and centre.

Of the special forms, the cube and rhombic dodecahedron are common to all classes of the cubic system. The remaining special forms in this class are the octahedron (fig. 25), tetrahexahedra (fig. 26), icositetrahedra and trisoctahedra (fig. 27). The 48-faced general form (fig. 28) is sometimes clearly displayed by crystals of diamond. Garnet, spinel and fluorite are other examples in this class.

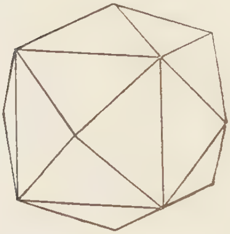

FIG. 26.—A tetrahexahedron.

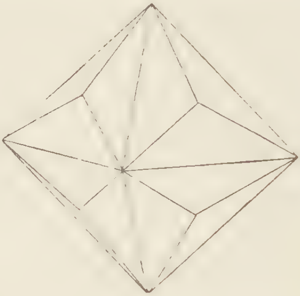

FIG. 27.—A trisoctahedron.

Didodecahedral (diploidal) class

Symmetry: 3 digonal axes, 4 trigonal axes, 3 planes (at right angles to the digonal axes) and centre.

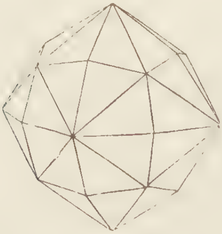

FIG. 28.—A hexoctahedron.

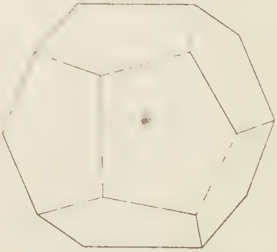

FIG. 29.—A pentagonal dodecahedron.

A characteristic special form is the pentagonal dodecahedron (fig. 29) sometimes called a pyritohedron, as it is often well displayed by pyrites, a prominent member of the class.

Hextetrahedral class

Symmetry: 3 digonal axes, 4 trigonal axes, 6 planes.

There is no centre of symmetry, and the tetrahedron is a characteristic special form. Blende (fig. 5) is an example of this class.

4 DISTORTED GROWTH

The illustrations used so far have all represented the particular crystals in question as developing with an ideally symmetrical morphology, all the faces of a single individual which belong to the same form being identical in size and shape. Unfortunately, natural crystals frequently depart from this ideally symmetrical growth and show instead a variable degree of distortion. The ideal regular octahedron presents eight equilateral triangular faces, but crystals of a substance such as diamond or spinel of this habit may be shaped as in fig. 30 or fig. 31. Such distortion appears at first sight to invalidate completely the preceding discussion of crystal symmetry, but it was established by the work of crystallographers in the seventeenth and eighteenth centuries that, though individual faces may vary in size and shape from one specimen to another of a given substance, the *angles between* corresponding faces retain a constant value. These interfacial angles can be measured by means of an instrument known as a goniometer, but the full interpretation of such measurements usually necessitates the use of a diagrammatic method of plotting the results. Such methods are rarely needed in the study of gemstones and will not be further discussed here; a more detailed account will be found in Chapter II of the preceding (twelfth) edition of this book. With the exception of occasional rare examples, of unusual habit or of extreme distortion, most natural crystals of gem materials will be readily recognized at sight after a little practice.

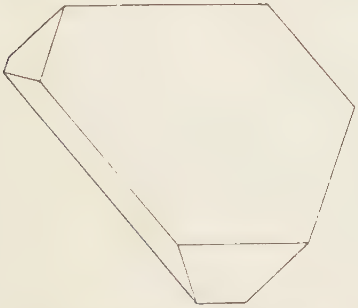

FIG. 30.—A distorted octahedron.

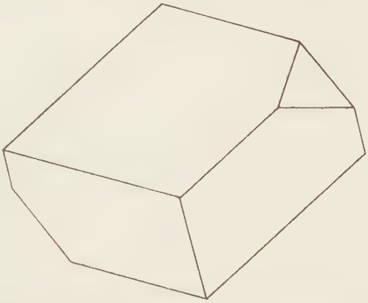

FIG. 31.—A second example of a distorted octahedron.

5 CRYSTALLOGRAPHIC AXES AND FACIAL INDICES

For purposes of description the position of any face on a crystal is referred to an axial system of three straight lines intersecting in an origin, after the manner of solid geometry. These straight lines are termed *crystallographic axes.* In each system the axes are chosen parallel to possible edges of the crystal and also, where the symmetry permits, parallel to prominent axes of symmetry.

In the cubic system the crystallographic axes are three equal orthogonal axes—a_1, a_2, a_3—normal to the faces of the cube. In the tetragonal system the axes are again orthogonal, but the vertical axis c (parallel to the tetragonal axis of symmetry) differs in length from the two equal horizontal axes a_1 and a_2. The value of the *axial ratio* c/a for each particular species is determined by selecting as a *parametral plane* a prominent crystal face which cuts all three axes. Thus for zircon $c/a =$ 0·6404 : 1, whilst for anatase $c/a =$ 1·777 : 1. In the orthorhombic system three unequal orthogonal axes, a, b, c, parallel to the three digonal axes of symmetry, are used; for topaz, $a : b : c =$ 0·5285 : 1 : 0·4770. In the monoclinic system it is no longer possible to use an orthogonal set of crystallographic axes; the a axis is inclined downwards in front at an angle β, greater than 90°, from the vertical c axis within the plane of symmetry, the b crystallographic axis being parallel to the digonal axis of symmetry. The triclinic system has the most general arrangement of crystallographic axes, three unequal axes, a, b, c, which are inclined at

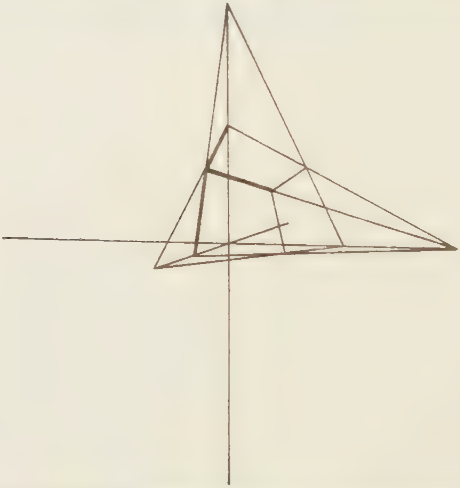

FIG. 32.—Intercepts on the axes by faces of the icositetrahedron {211}.

angles α, β, γ, none of which is 90° (whence derives the alternative name, anorthic, for this system). In the hexagonal and trigonal systems it is found convenient to use a system of four crystallographic axes; three equal horizontal axes, a_1, a_2, a_3, at angles of 120° to each other and a vertical axis c at right angles to the plane containing these axes (and hence parallel to the hexagonal or trigonal axis of symmetry).

To define the positions of faces with reference to these crystallographic axes a system of *facial indices* is used, termed *Miller Indices*, after William Hallowes Miller (1801–80). The parametral plane, chosen to define the unit intercepts $a : b : c$, is given the index 111 (one one one). The index of any other crystal face is $h\ k\ l$, where a/h, b/k, c/l are the intercepts made by that face on the three axes. Thus in the cubic system, a face of the octahedron having been selected as the 111 plane, it is found that the slope of a face of the icositetrahedron is such, fig. 32, that its intercepts are $a/2$, $a/1$, $a/1$, and hence its index is 211 (two one one); the index of a face of the trisoctahedron, fig. 33, is 221. The three figures of an index are written in an order referring to the axes on a recognized scheme, an intercept on the negative side of an axis being indicated by a bar over the corresponding figure; thus the index of the front lower right-hand face of an octahedron (fig. 34) is $11\bar{1}$ (one one bar-one). An infinite intercept, corresponding to parallelism of the face to a particular axis, gives the index figure 0 (nought); the cube consists of six faces, 100, 010, 001, $\bar{1}00$, $0\bar{1}0$, $00\bar{1}$. The assemblage of all

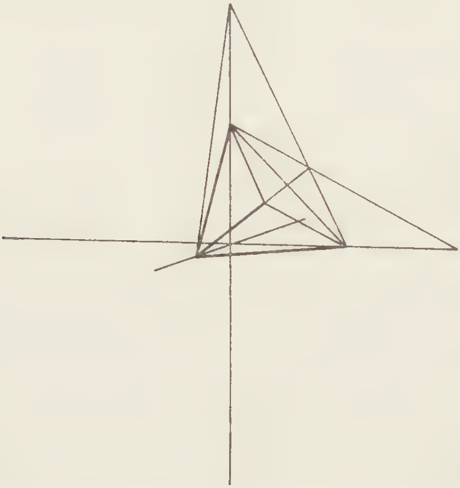

FIG. 33.—Intercepts on the axes by faces of the trisoctahedron {221}.

the faces constituting a form may be indicated by writing the index of any one of its faces enclosed by 'curly brackets'; the cube is the form {100}, the octahedron the form {111}.

In the cubic system, a face of the octahedron, chosen as the parametral plane, makes equal intercepts on all three axes. In systems of lower symmetry no such crystal face exists, but none the less it is found that the indices of all faces, when referred to a selected parametral face, can always be expressed as small whole numbers. For topaz it has already been seen that the selected parametral plane defines axial ratios $a : b : c = 0{\cdot}5285 : 1 : 0{\cdot}4770$. Two other common terminal faces make intercepts in the ratios $0{\cdot}5285 : 1 : 0{\cdot}9540$ and $\infty : 1 : 0{\cdot}9540$ respectively; by dividing these intercepts into the parametral intercepts, and clearing of fractions, the indices of these faces are derived as 221 and 021 respectively. The discovery of these simple relationships throughout crystals of all degrees of symmetry led to the foundation of the *Law of Rational Indices* (the Miller Indices can always be expressed as whole numbers or zero), and further to important conclusions concerning the internal structure of crystals which will be described later.

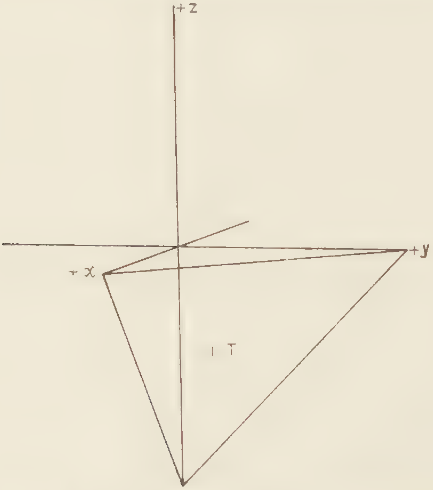

FIG. 34.—Illustrating the convention for positive and negative indices.

In trigonal and hexagonal crystals, where a system of four crystallographic axes is used, each index consists of four figures; the third figure is, of course, not independent (the intercept on the third horizontal axis is determined by those on the other two, and in fact the sum of the first three figures of an index of this type is always zero). Either of the planes $10\bar{1}1$ or $11\bar{2}1$ may be considered as the parametral plane in this notation.

6 TWINNING

Crystals of many minerals are often found to be composed of two individuals, which are alike in form and are so related in position that the one is the reflection of the other across a certain plane, the twinning-plane, or may be brought into parallelism with it by a rotation of 180°, or a half turn, about some line, the twinning-axis, which may be an edge or the perpendicular to a face; in the case of symmetrical crystals the line may be defined in either way. Such composite crystals are called twins or macles. The twinning-plane is at right angles to the twinning-axis, and usually is the same as the composition-plane, that is the one common to the two individuals. Some species have more than one twin law; calcite, for instance, has two common and two rare directions of twinning. It is conceivably possible that, when the two individuals composing a crystal cannot be brought into parallelism by reflection across a plane or a half turn about an axis, they may be related by twinning to an intermediate individual which is too small to be detected.

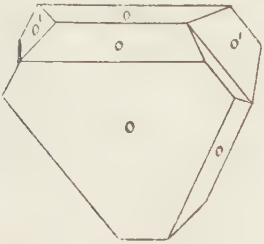

FIG. 35.—A twinned octahedron.

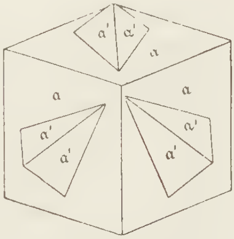

FIG. 36.—Interpenetrant twinning in fluor.

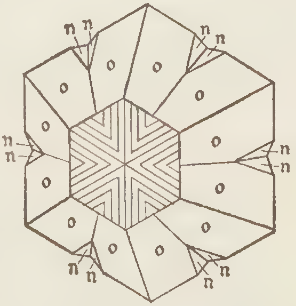

FIG. 37.—A pseudo-hexagonal twinned crystal of chrysoberyl.

Sometimes the two individuals are in contact, as, for instance, in the familiar twinned octahedron (fig. 35) characteristic of diamond and spinel, and sometimes they are interpenetrant, as in the familiar twins of fluor (plate XX and fig. 36). The interpenetration may, indeed, be hidden and not discernible from the morphology of the crystal, as in the case of quartz. Sometimes the twinning is repeated, as in the case of chrysoberyl (fig. 37) or aragonite, and consequently the crystals simulate a higher symmetry than that which they really possess. Sometimes the individuals are in the form of thin lamellae, which are many times parallelly repeated; this mode of twinning is termed polysynthetic twinning, and is often recognizable by a series of parallel striations which are visible on a face.

It should be noted that, although the relative orientation of the two portions of a twinned crystal can be described in terms of a rotation, most twinned crystals have grown as such and no rotation has actually occurred. During growth a part of the structure has been built up in reversed orientation. In an enantiomorphous substance, such as quartz, one type of twinned crystal consists of two portions of opposite hand; such a twin must be described in terms of reflection across the twinning-plane, since no rotation can bring a right-handed structure into coincidence with a left-handed one.

Sometimes after the formation of a crystal it has been subjected to considerable pressure, which has resulted in the inversion of the structure in certain lamellae. This phenomenon is known as secondary twinning, since in these instances actual movement has taken place in the structure since the original growth. Such crystals tend to split along the planes separating successive individuals, and they are then said to have a plane of parting. Corundum is a conspicuous example of this property among gemstones; its plane of parting is parallel to the basal face. In boules of synthetic corundum, owing to stresses set up in the course of cooling, secondary twinning appears to develop in a section through the axis and the boules tend to split in this direction.

7 ISOMORPHISM

It is an important feature of crystallization that the chemical composition may vary considerably without any fundamental alteration in the general framework formed by the constituent atoms. In groups of this kind the crystal form remains the same or nearly so, and, unless the crystals happen to belong to the cubic system, there is a gradual change in the interfacial angles, and in the physical properties—refractive indices and specific gravity—as the chemical composition alters. This is the property known as isomorphism, so called from the Greek words ἴσος (equal) and μορφή (form).

The most familiar example among gemstones of an isomorphous group is the garnet family: grossular, $Ca_3Al_2(SiO_4)_3$; pyrope, $Mg_3Al_2(SiO_4)_3$; almandine, $Fe_3Al_2(SiO_4)_3$; spessartite, $Mn_3Al_2(SiO_4)_3$;

andradite, $Ca_3Fe_2(SiO_4)_3$; and uvarovite, $Ca_3Cr_2(SiO_4)_3$. As is pointed out in a later chapter (p. 329), no garnet analysis will correspond exactly with any one of these formulae, but the composition of any garnet may be explained as consisting of various proportions of two or more of the principal members of the family stated above. It is clear then that aluminium is replaceable to any extent by ferric iron or chromium and in the same way calcium by magnesium, ferrous iron or divalent manganese. Indeed, the replacement of aluminium by ferric iron, and of calcium by ferrous iron or magnesium is constantly to be found among minerals, and is the explanation of the variation in refractive indices and specific gravity characterizing certain species, for example olivine (peridot) and spinel. Olivine is in fact a group with two end members: forsterite, magnesium silicate, and fayalite, iron silicate (p. 348). The variation in the composition of spinel is discussed in a later chapter (p. 323).

An example of another kind is provided by the important group of rock-forming minerals, the plagioclase-feldspars, a series which can be explained as an isomorphous mixture in any proportion of albite, $NaAlSi_3O_8$, and anorthite, $CaAl_2Si_2O_8$. In this instance two pentavalent pairs, NaSi and CaAl, are mutually replaceable.

In some substances there appears to be a very free replacement of atoms by one another. In tourmaline, for example, in addition to the replacement of sodium by calcium, we find a general interchange between aluminium, titanium, iron, manganese, magnesium and lithium, and between oxygen, hydroxyl and fluorine. In fact, the most critical factor which regulates the feasibility of an atom finding a place in a particular crystal structure is its size (p. 48).

8 POLYMORPHISM

In the previous section we considered instances in which the chemical composition varied considerably, while the crystal form remained constant or nearly so. (The word 'form' is used here in a general sense, and not with the special crystallographic meaning defined on p. 32.)

In this section we are concerned with the converse: a similarity in the chemical composition, but a great disparity in the crystal form and generally in the physical properties. If the chemical compound occurs in two different crystal forms, the substance is said to be dimorphic, and if in three, trimorphic; the general phenomenon is termed polymorphism.

The most striking example of polymorphism is provided by diamond and graphite; both are essentially pure carbon in composition, but, whereas the former is by far the hardest of natural substances and is invaluable for cutting hard material, the latter is extremely soft, and has valuable properties as a lubricant for heavy loads. Calcium carbonate is found in two different forms: calcite and aragonite, of which the former occurs in rhombohedral crystals and the latter in orthorhombic crystals, which, however, are often repeatedly twinned, so that they simulate hexagonal symmetry. Again, the iron sulphides, pyrites and marcasite, are alike in chemical composition, but the former crystallizes in the cubic system, and the latter in the orthorhombic system. The native oxide of titanium occurs as three different minerals: rutile, anatase and brookite (p. 412).

C. CRYSTAL STRUCTURE

The internal arrangement of crystals has been the subject of keen speculation from the very dawn of crystallographical science. In the eighteenth century R. J. Haüy (1743–1822) was led, by the way in which calcite may be cleaved into rhomboids with apparently no lower limit to the smallness of size, to suppose that its crystals were built up of innumerable tiny bricks of that shape, and that other than the rhomboid faces have resulted from a regular stepping of the bricks backwards, the resulting corrugations being so infinitesimally small that the corresponding faces appear to be optically smooth. The establishment of the Law of Rational Indices (p. 42) as universally applicable to crystals of all degrees of symmetry finally made it abundantly clear that all crystals could be considered as being built up in this way by the endless repetition of a fundamental unit. Expanding knowledge of the atomic structure of matter, however, made it equally clear that the fundamental unit could not be viewed as one of Haüy's solid bricks, but rather that it must be a *unit of pattern*, a three-dimensional motif by the repetition of which the structure of the whole crystal is built up, just as a two-dimensional motif is repeated throughout the pattern on a sheet of wallpaper. This three-dimensional unit of pattern is contained within the *unit cell* of the crystal. The contents of the unit cell determine the composition of the resultant crystal, and the disposition of the contents within a unit cell of given symmetry and dimensions determines the resultant symmetry and morphology of the whole crystal. The reason for the absence, from amongst crystals, of pentagonal symmetry and of symmetry higher than hexagonal, will now be readily apparent; even thinking in terms only of two dimensions, it will be realized that squares, rectangles, parallelograms, equilateral triangles and regular hexagons are the only figures which can be packed regularly to form a closed pattern.

The geometrical theory of three-dimensional structures of this type had been fully worked out before the end of the nineteenth century. Up to the close of the first decade of the present century, however, crystallographers were unable to investigate these patterns directly, and fully realized that their inability to do so arose from the smallness of the dimensions of the unit cells in comparison with the wave-lengths of visible light. In 1912 M. von Laue and his assistants first demonstrated that a beam of X-rays suffered diffraction when passed through a crystal. The diffracted beam, when received on a photographic plate, gave rise to a pattern of spots, the symmetry of which was directly related to the symmetry of the crystal structure about the path of the transmitted beam. The Laue procedure, as a means of investigating crystal structures, has since been largely superseded by other methods which have enabled X-ray crystallographers to determine the size and shape, and the disposition of the contents, of the unit cells of most crystalline substances. In the method of *powder photography* the X-ray beam is transmitted through a small sample of the material in the form of a very fine powder. The photograph shows a diffraction pattern of lines, the distribution and intensity of which are characteristic of a particular crystal structure, and the procedure has proved valuable in cases of critical identification (the necessary small quantity of material can be scraped from the girdle of a cut gem with little damage). It is unnecessary, however, to attempt here to explain these methods in detail, though a knowledge of some of the results of X-ray analysis is helpful in understanding the properties of gem materials.

I TYPES OF BOND

A crystal is held together as a solid structure by reason of forces between the constituent atoms. These interatomic forces are termed atomic bonds, and may be of several different types. In many inorganic substances, including the majority of the minerals used as gemstones, the bond is *ionic*: the individual atoms are ionized, with either positive or negative charge, and the ionic bond results from the attraction between ions of opposite charge, together with repulsion between those of like charge. In fluor, for example, each positively charged calcium ion is surrounded symmetrically by eight negatively charged fluorine ions disposed at the corners of a cube (fig. 38); in silicates, each silicon ion is surrounded by a tetrahedral group of oxygen ions. Diamond, consisting entirely of atoms of the element carbon, is an example of a different type of atomic bond; the like atoms are linked together by a *homopolar* (or *covalent*) *bond*, arising from the sharing of electrons between adjacent atoms. Two further types of bond call for only brief mention, being of little importance in gem materials. In metal crystals the *metallic bond* arises from the presence of an electron cloud surrounding an aggregate of positively charged metal ions. Finally, whilst in the many crystal structures belonging to the types so far described there is no true chemical molecule existing as a unit in the structure, molecular groups do exist in some crystals, particularly of organic substances. The bonds within each molecule are largely homopolar, but the molecules are held together in the whole structure by *residual (van der Waals) bonds*.

In many simple substances the bond is uniformly ionic, or uniformly homopolar, throughout the crystal. In more complex structures bonds of different types may be present in different parts; this is frequently the case when a chemical radicle exists actually as an entity within the structure. In a carbonate such as calcite, for example, each carbon atom is united by homopolar bonding to three oxygen atoms in a plane triangular group, and these groups are bonded ionically to the metal ions.

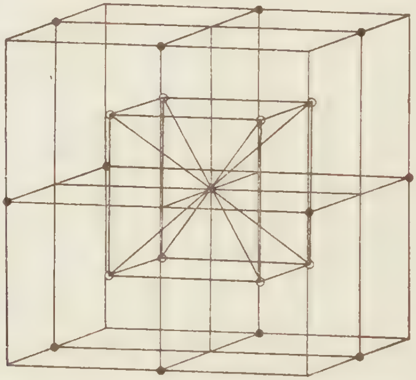

FIG. 38.—A portion of the structure of fluor. Calcium ions are represented by full circles and fluorine ions by open circles.

2 IONIC AND ATOMIC SIZE

When two ions are brought very close together the repulsive force between them rises rapidly, so that there is a minimum possible distance of approach of their centres. It has thus proved possible to form a simple picture of ionic structures in terms of the packing in contact of incompressible spheres. The 'radius' of a given ion depends upon the chemical element in question and upon the electrostatic charge which it carries, being small for positively charged ions (*cations*) such as Si^{+4}, Al^{+3}, Fe^{+2}, and large for negatively charged ions (*anions*) such as F^{-1} and O^{-2}. The disposition of ions in a structure can be readily visualized from packing drawings in which the ions are represented with radii in correct ratio. In the drawing of fluor (fig. 39), the cubic group of eight large F^{-1} ions surrounds a central Ca^{+2} ion, an arrangement which is continued throughout the crystal structure. A smaller cation might be surrounded by six anions at the coigns of an octahedron, a still smaller one by four anions grouped tetrahedrally. This latter arrangement is fundamental in the structures of silicates, the small Si^{+4} ion fitting inside a tetrahedral group of O^{-2} ions. The possibility of isomorphous replacement (p. 44) in such structures is largely determined by the ionic radius of the substituting element. In many silicates Al^{+3} replaces some of the Si^{+4} within the tetrahedra of oxygen, the altered electrostatic charge being compensated by other replacements elsewhere in the structure—in the plagioclase feldspars, for example, Ca^{+2} concurrently replaces some of the Na^{+1}. This view of replacement by ionic size helps greatly towards an understanding of the reason for the occurrence of small amounts of diverse elements as 'impurities' in many minerals.

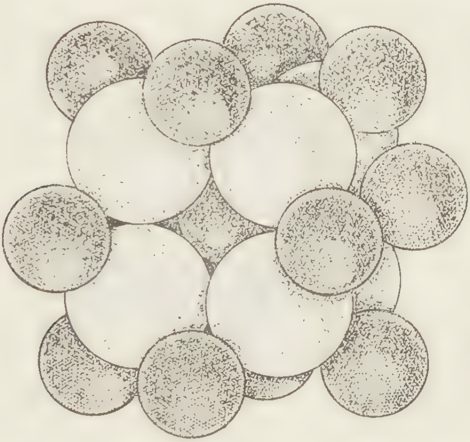

FIG. 39.—A packing drawing of a portion of the structure of fluor, showing the eight anions grouped around a cation.

Packing drawings may be useful even if the bonding in a structure is not ionic—half the distance between centres of like atoms in many symmetrical structures with homopolar or metallic bond may be considered as the appropriate atomic radius. Fig. 40 illustrates a packing drawing of diamond constructed on this principle.

3 ATOMIC STRUCTURE AND PHYSICAL PROPERTIES

Many of the physical properties which are of significance in gemstones are immediately related to the type of atomic structure and nature of bonding. Weak bonding results in soft substances, and the hardness of many gemstones is due to the presence of predominantly ionic bonding. A homopolar bond may give still greater hardness, well exemplified by diamond. Cleavage usually takes place parallel to planes in the structure in which the atoms are most closely grouped, and hence across directions of maximum separation of adjacent atoms. If more than one type of bond is present in a structure, cleavage will occur across the weakest bonds; the softness and cleavability of graphite, chemically the same as diamond, are due to the weak residual bonding between layers of carbon atoms within which the bonding is strong and close.

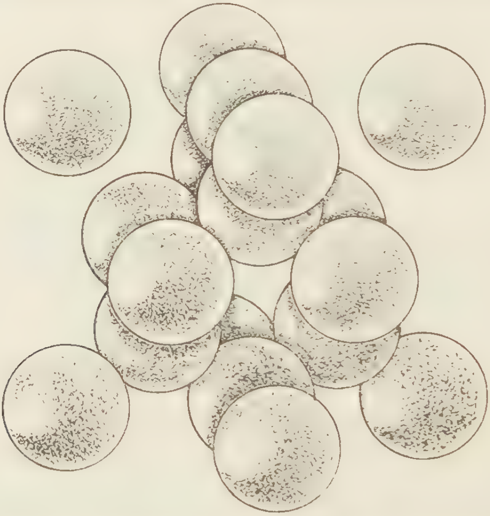

FIG. 40.—A packing drawing of a portion of the structure of diamond. (The apparently unsupported atoms are in contact with others in the continuous structure.)

Optical properties, also, are closely related to the structure. The refractive index (p. 52) of diamond and of blende is high because of the homopolar nature of the bonding. The symmetry of the structure determines the symmetry of the optical properties (p. 88); the presence of parallel planar groups, or sheets, of atoms throughout a structure, for example, will usually result in a high degree of anisotropy, the optical and other physical properties varying strongly with direction within the crystal.

III

REFLECTION, REFRACTION AND COLOUR-DISPERSION

It is obvious that, since a stone suitable for ornamental use must appeal to the eye, its most important characters from this point of view are those which depend upon light; indeed, the whole art of the lapidary consists in shaping it in such a way as to show these qualities to the best advantage. To understand why certain forms are given to a cut stone it is important to ascertain what becomes of the light that falls upon its surface. Incidentally we shall find that the action of the stone upon the light results in effects which are of very great service in distinguishing, especially in the cut form, one species of gemstones from another.

The behaviour of light when impinging upon the surface separating two media[1] is much the same whatever be the nature of the media. Everyday experience with a plane mirror teaches us that, when light is returned, or reflected, as it is usually termed, from a plane or flat surface, there is no alteration in the size of objects viewed in this way, but that the right and the left hands are interchanged; the object and its image are said to be enantiomorphous. If a second plane mirror be used for viewing the image in the first, the second image is the same as the object, although it is impossible to bring the eyes of the second image into line with our own. We notice that our image in a plane mirror is apparently just as far behind it as we are before it.

In fig. 41 *MM′* is a section of a plane mirror, and *O′* is the image

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[1] The term, medium, is understood by physicists to express any form of matter through which light passes, and includes solids such as glass, liquids such as water and gases such as air. Since light pervades the whole of space, it became necessary to postulate some entity for its action. The term ether was first adopted by Sir Isaac Newton, P.R.S. (1642–1727) in this sense. Conceptions of the properties of ether have changed vastly since Newton described it as 'exceedingly more rare and subtile than the air and exceedingly more elastick and active', but for those who believe that a medium of some kind must exist the term is still useful. Modern philosophy is tending to believe that the various conditions of matter are but modifications of the ether.

of the hand, *O*, as seen in the mirror. The ray from *O* reaches the eye, *E*, by way of *m* on the surface of the mirror, but it appears to come from *O′*. Since the line *OO′* is perpendicular to the mirror, and *O* and *O′* are equally distant from it, it follows from elementary geometry that the angle, *i′*, which the reflected ray makes with *mn*, the normal to the mirror, is equal to *i*, the angle which the incident ray makes with the same direction.

Everyday experience teaches us further that the case is less simple when light actually crosses the surface bounding two media and passes from the first into the second medium. Thus, if we look down into a bath containing water, the bottom of the bath appears to be higher than it really is, and if a stick be plunged into the water at an angle, it appears to be bent at the surface. Since the stick itself has not been bent, light evidently suffers some change in direction as it passes into the water or emerges from it. The passage of light from one medium to another was studied by Snell[1] early in the sixteenth century, and he enunciated the following laws of refraction:

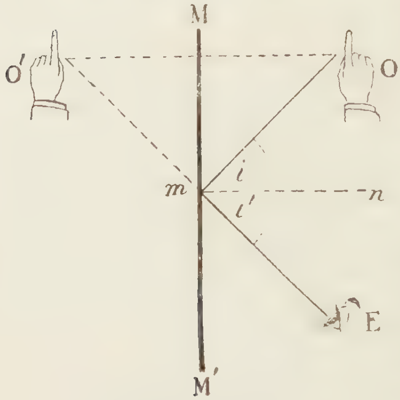

FIG. 41.—Reflection at a plane mirror.

(*a*) The refracted ray lies in the plane containing the incident ray and the normal to the plane surface separating the two media.

It will be noticed that the reflected ray obeys this law also.

(*b*) The angle, *r*, which the refracted ray makes with the normal, is related to the angle, *i*, which the incident ray makes with the same direction, by the equation

$$n \sin i = n' \sin r \qquad . \quad . \quad . \quad . \quad (1)$$

where *n* and *n′* are the constants for the two media which are known as the indices of refraction or the refractive indices. Since in complex substances the refractive index varies with the direction, as is explained later (p. 81), it is convenient to use the term, refractivity, for the present to denote the average index of refraction.

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[1] Willebrord Snell van Roijen (1591–1626). The laws of refraction were first published by Descartes (René du Perron Descartes, 1596–1650) as his own after Snell's death, but the latter was undoubtedly their discoverer.

This simple trigonometrical relation may be expressed in geometrical language. Suppose we consider the plane section, *SOS′* (fig. 42), at right angles to the surface bounding the two media, which contains the incident ray, *IO*; then Snell's first law tells us that the refracted ray, *OR*, also lies in this plane. Draw the normal, *NON′*, and with centre, *O*, and an arbitrary radius describe a circle, intersecting the incident and refracted rays in the points, *a* and *b*, respectively; let drop perpendiculars, *ac* and *bd*, upon the normal, *NON′*. Then we have

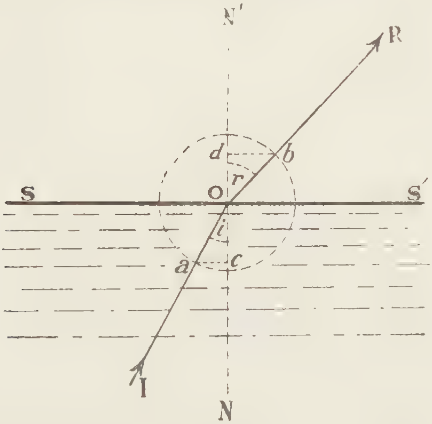

FIG. 42.—Refraction across a plane surface.

$n \,.\, ac = n' \,.\, bd$, whence we see that, if n be greater than n', ac is less than bd, and therefore that, when light passes from one medium into another which is less optically dense, it is bent, or refracted, away from the normal on its passage across the boundary.

We shall find in a later chapter that, in order to understand the complexities of the transmission of light in a doubly-refractive crystal, it is better to suppose it to have a wave-motion, and it is not malapropos to consider the application of this theory to the simple case of the passage of light from one simple medium to another. In fig. 43 *SOO′S′* is a section at right angles to the bounding plane of the two media; *IO*, *I′O′* represent the incident wave, and *OR*, *O′R′* the refracted wave. *OP* and *O′P′*, which are drawn perpendicular to *I′O′* and *OR* respectively, represent the positions when the wave-front reaches the boundary at *O* and leaves it at *O′*. On the assumption that the lower medium in the figure is, as before, the optically denser one, the velocity, v, of the wave in it is less than the velocity, v', in the other medium (the velocity in a medium is inversely proportional to the refractive index), and accordingly PO', which is proportional to v, is less than OP', which is proportional to v'. The angles POO' and $P'O'O$ are i and r, the angles of incidence and refraction. Since OO' is common to the two triangles, POO' and $P'OO'$, and the angles at P and P' are right angles, we have $v/\sin i = v'/\sin r$, which is the same as $n \sin i = n' \sin r$.

When light impinges upon the surface between two media in the manner which we have been considering, some of it is shown to be refracted on passing into the second medium; but it must be noted that at least some of it is reflected and remains in the first medium, and in certain circumstances, as we shall shortly see, none of the light emerges into the second medium. The ratio between the reflected and refractive portions is completely related to the angle of incidence and the refractive indices of the media. It is a point to which we shall return when we come to consider the lustre of stones.

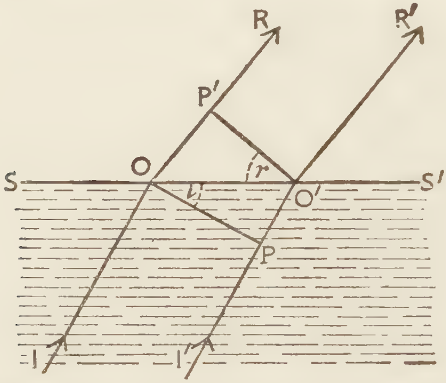

FIG. 43.—Passage of a light-wave from one medium to another.

We may now consider the course of the rays corresponding to different angles of incidence when light passes from one medium to another—for instance, from water to air. Corresponding to a ray with a small angle of incidence, such as I_1O (fig. 44), part is reflected in the direction, OI'_1, in the first medium and the remainder is refracted in the direction, OR_1, in the second medium. Similarly, for the ray, I_2O, part is reflected along OI'_2 and the remainder is refracted along OR_2. Since, in the case selected, light is passing from a medium into one that is optically less dense—that is, has a lower refractive index—the angle of refraction is greater than the angle of incidence. Consequently, the refracted ray which grazes the boundary plane corresponds to a particular ray, I_cO. For rays, such as I_3O, which have a larger angle of incidence there is no corresponding ray in the second medium; or, in other words, the ray is wholly or totally reflected within the denser medium. The critical angle, I_cON, which is called the angle of total-reflection, is very simply related to the refractive indices of the two media; for, since r is now a right angle, $\sin r = 1$, and equation (1) becomes

$$n \sin i = n' \quad . \quad . \quad . \quad . \quad (2)$$

Hence, if the angle of total-reflection be measured and one of the refractive indices be known, the other can easily be calculated.

The phenomenon of total-reflection may be appreciated if we hold a glass of water above our head and view the light of a lamp, say on a table, reflected from the under surface of the water. This reflection will be found to be incomparably more brilliant than that given by the upper surface.

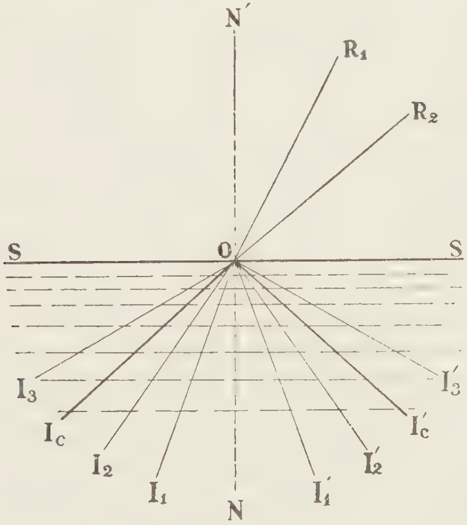

FIG. 44.—Total-reflection.

The refractive index of air is taken as unity; strictly, it is that of a vacuum, but the difference is too small to affect the accuracy of even very delicate determinations. Every substance has refractive indices that vary according to the colour, that is, the wave-length, of the light used, and it is customary to select as the standard the yellow light emitted by a sodium flame,[1] which happens to be the colour to which

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[1] The sodium spectrum contains a strong doublet (5896, 5890 Å) in the yellow region. Two corresponding dark lines, D_1 and D_2, are prominent in the solar spectrum, representing the absorption lines of sodium vapour. (If the reader is unacquainted with the notation used here he should refer to p. 101.)

our eyes are most sensitive. If a suitable electric supply be available an intense yellow light may be obtained from a sodium-vapour lamp; or alternatively a yellow flame can be obtained by volatilizing a bead of bicarbonate of soda in the flame of a bunsen gas-burner.

A glance at the list of refractive indices of gemstones in Part IV shows what a potent weapon is the measurement of the refractive index in the determination of the species to which a cut stone belongs. How this measurement may best be effected is discussed in the next chapter. Although the refractive indices are defined as a physical constant, they may vary within quite wide limits for different specimens of the same mineral species owing to the latitude in the chemical composition resulting from the isomorphous replacement of one element by another without any fundamental alteration in the crystal structure. Some variation in the refractive index may even occur in different directions within the same stone; it results from the remarkable property of splitting up an incident ray of light into two rays, which is possessed by all crystallized substances which do not belong to the highest (cubic) class of symmetry. The phenomenon of birefringence or double refraction is discussed in a later chapter.

Upon the fact that the refractive index of a substance is different for light of different colours depend such familiar phenomena as the splendour of the rainbow and the fire of the diamond. When white light passes into a stone, it is no longer white, but is split up into a spectrum. Except in certain anomalous substances, which are, however, not among gemstones, the refractive index increases progressively as the wave-length of the light decreases, and consequently a normal spectrum is violet at the one end and passes through blue, green, yellow and orange to red at the other end. The angular width of the spectrum, which may be measured by the difference between the refractive indices for the extreme red and violet rays, also varies, although on the whole it increases with the refractive index. It is this colour-dispersion, as this difference is termed, that determines the fire—a character of the utmost importance in colourless transparent gemstones, which but for it would be lacking in interest. Diamond excels all natural colourless gemstones in this respect, although it is closely followed by zircon, the colour of which has been driven off by heating; it is, however, surpassed by the nearly colourless synthetic rutile and synthetic strontium titanate and by three coloured species: demantoid (green garnet), sphene (titanite) and, above all, cassiterite (tinstone).

The colour-dispersion of the more important gemstones is given in the table in Part IV. As the standard of reference the lines *B* (6870 Å) and *G* (4308 Å), which lie very near the red and the violet ends of the visible spectrum respectively, have been selected for use in the text, but in the table the values corresponding to the smaller interval, *C* (6563 Å) to *F* (4861 Å), have been added, because it is the one used in the case of optical glasses, and comparison between them and gemstones in regard to dispersive power is thereby facilitated. It must be remarked that, in order to determine accurately the colour-dispersion of a stone, it is essential to use monochromatic light of wave-lengths as near as possible to the limits of the interval selected, either *B* and *G* or *C* and *F*. If for any stone the refractive index be plotted on a diagram against the wave-length, the result is not a straight line, or even approximately one, but a curve with varying curvature, as may be seen in the case of diamond (fig. 45). Figures for dispersion can be usefully compared only if they are measured between identical wave-length limits.

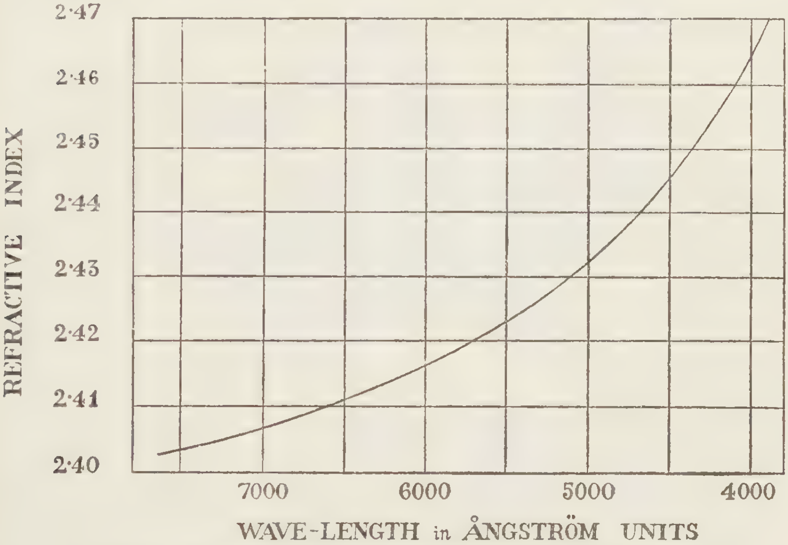

FIG. 45.—Diamond: refractive index wave-length diagram.

IV

MEASUREMENT OF REFRACTIVE INDICES

Several methods are available for the measurement of refractive indices. The most generally useful is based upon the very simple relation which was found in the preceding chapter to subsist between the ratio of the refractive indices of the two media in mutual contact and the critical angle at total reflection (p. 55); it is, however, restricted in use to a range limited by the refractive index of the constant medium. The instruments employed are termed refractometers. Some designs yield direct readings of the refractive indices. In others, the critical angle is measured on the instrument, and the value of the corresponding refractive index is determined by computation (or graphically, using a nomogram); these latter have sometimes been distinguished as total-reflectometers. In addition to the methods based on the principle of total reflection, certain other procedures are described later in the chapter, and their special advantages and disadvantages are set out.

A. TOTAL-REFLECTION

1 REFRACTOMETER

We have seen from equation (2) (p. 55), connecting the critical angle at total-reflection with the refractive indices of the two media in mutual contact, that, if the denser of them be constant, the refractive indices of all less dense media may be easily calculated from a determination of the corresponding critical angles. In refractometers the constant is normally a glass with a high refractive index, but for special purposes an isotropic mineral, such as blende or even diamond, with a still higher refractive index may be substituted. There still, however, remains the difficulty that the instrument is restricted in its application to stones that have lower refractive indices than the liquid needed to maintain optical contact between the stone under test and the constant substance, and no liquid has yet been found with a sufficiently high refractive index for use in such an extensive range which does not suffer from grave disadvantages that militate against its utility.

Since all refractometers are based upon the same fundamental principle, it will be convenient to discuss the one devised by the author in 1906, which was the first to enable accurate measurements to be made of the refractive indices of faceted gemstones (fig. 46). In order to facilitate the observations, a totally-reflecting prism has been inserted between the two lenses of the eyepiece. The eyepiece may be adjusted to suit the individual eyesight; but for observers with exceptionally long sight an adapter is provided, which permits the eyepiece being drawn out to the requisite extent. The refractometer should be held so that the light from a window or other source of illumination enters the instrument by the lenticular opening underneath (fig. 47). Good, even illumination of the field may also very simply be secured by reflecting light into the instrument from a sheet of white paper laid on a table. On looking down the eyepiece we see a scale (fig. 48), the eyepiece being, if necessary, focused until the divisions of the scale are clearly and distinctly seen.

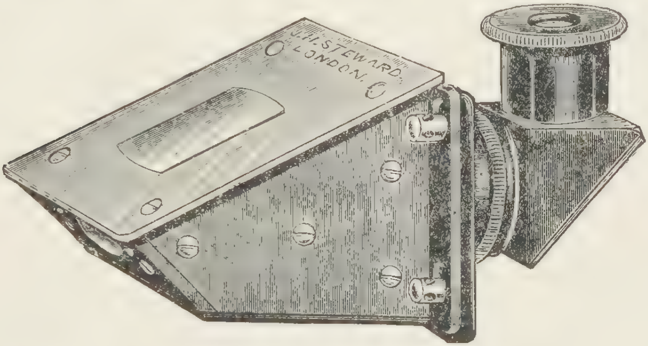

FIG. 46.—Herbert Smith Refractometer (*actual size*).

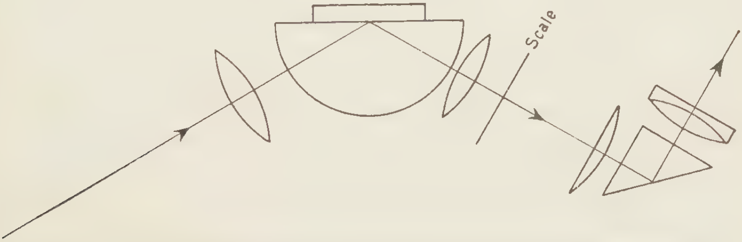

FIG. 47.—Diagram to show the principle of the refractometer.

Suppose, for experiment, we smear a little vaseline or similar fatty substance on the plane surface of the dense glass, which just projects beyond the level of the brass plate embracing it. The field of view is now no longer uniformly illuminated, but is divided into two parts (fig. 49): a dark portion above, which terminates in a curved edge, apparently green in colour, and a bright portion underneath, which is composed of totally reflected light. If we tilt the instrument downwards so that light enters the instrument from above through the vaseline, we find that the portions of the field are reversed (fig. 50) the dark portion being underneath and terminated by a red edge. It is possible so to arrange the illumination that the two portions are evenly lighted, and the common edge becomes almost invisible. It is therefore essential for obtaining satisfactory results that the plate and the dense glass be shielded from the light by

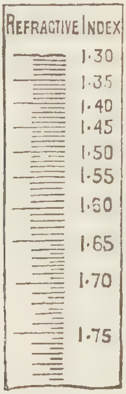

FIG. 48.—Scale of the Herbert Smith Refractometer.

FIG. 49.—Shadow-edge given by a singly-refractive substance.

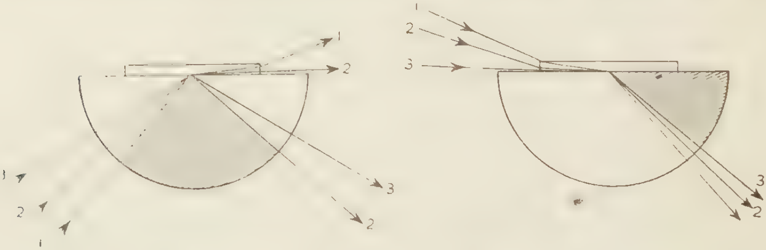

FIG. 50.—Formation of shadow-edge with alternative modes of illumination.

the disengaged hand. The shadow-edge is curved, and is, indeed, an arc of a circle, because spherical surfaces are used in the optical arrangements of the refractometer; by the substitution of cylindrical surfaces it becomes straight, but sufficient advantage is not secured thereby to compensate for the greatly increased complexity of the construction. The shadow-edge is coloured, because the relative colour-dispersion, $\frac{n_v - n_r}{n}$ (n_v and n_r being the refractive indices for the extreme violet and red rays respectively), of the vaseline differs from that of the dense glass. The dispersion of the glass is very high, and exceeds that of any stone for which it can be used. Certain oils have, however, nearly the same relative dispersion, and the edges corresponding to them are consequently almost colourless.

A careful eye will perceive that the coloured shadow-edge is in reality a spectrum, of which the violet end lies in the dark portion of the field and the red edge merges into the bright portion. The yellow colour of a sodium flame, which, as has already been stated, is selected as the standard for the measurement of refractive indices, lies between the green and the red, and the part of the spectrum to be noted is at the bottom of the green, and practically therefore at the bottom of the shadow, because the yellow and red are almost lost in the brightness of the lower portion of the field. If a sodium flame be used as the source of illumination, the shadow-edge becomes a sharply defined line. The scale is so graduated and arranged that the reading, where this line crosses the scale, gives the corresponding refractive index; the reading, since the line is curved, being taken in the middle of the field on the right-hand side of the scale. The refractometer therefore gives at once, without any intermediate calculation, a value of the refractive index to the second place of decimals, and a skilled observer may, by estimating the tenths of the intervals between successive divisions, arrive at the third place; to facilitate this estimation, the semi-divisions beyond 1·650 have been inserted. The range extends nearly to 1·800; for any substance with a higher refractive index the field is dark as far as the limit at the bottom.

A fat, or a liquid, wets the glass, that is, comes into intimate contact with it, but if a solid substance, such as a faceted stone (fig. 51), be tested in the same way, a film of air would intervene and entirely prevent an observation. To displace it, a drop of some liquid which is more highly refractive than the substance under test must first be applied to the plane surface of the dense glass. The most generally convenient liquid for the purpose is methylene iodide (CH_2I_2), which, when pure, has at ordinary room-temperatures a refractive index of 1·742. It is almost colourless when fresh, but turns reddish-brown on exposure to light. If desired, it may be cleared in the manner described below (p. 129), but the film of liquid actually used is so thin that this precaution is scarcely necessary. If we test a piece of ordinary glass—one of the slips used by microscopists for covering thin sections is very convenient for the purpose—first applying a drop of methylene iodide to the plane surface of the dense glass of the refractometer, we notice a coloured shadow-edge corresponding to the glass-slip at about 1·530 and another, almost colourless, at 1·742, which corresponds to the liquid. If the solid substance, which is tested, be more highly refractive than methylene iodide, only the latter of the shadow-edges is visible, and we must utilize some more refractive liquid. We can, however, raise the refractive index of methylene iodide by dissolving sulphur[1] in it; the refractive index of the saturated liquid, when hot, is about 1·800, but when the liquid cools, the refractive index falls to about 1·785, as the excess sulphur crystallizes out. The pure and the saturated liquids can be procured with the instrument, the bottles containing them being japanned on the outside to exclude light and fitted with dipping-stoppers, by means of which a drop of the liquid required is easily transferred to the surface of the glass of the instrument. So long as the liquid is more highly refractive than the stone, or whatever may be the

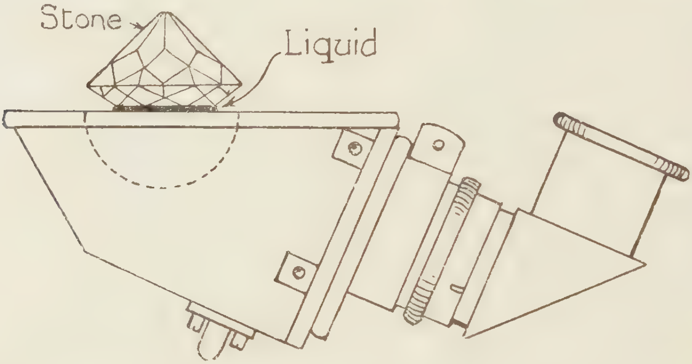

FIG. 51.—Faceted stone in position on the Herbert Smith Refractometer.

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[1] Methylene iodide must be heated almost to boiling-point to enable it to absorb sufficient sulphur; but caution must be exercised in the operation to prevent the liquid boiling over and catching fire, the resulting fumes being far from pleasant. It is advisable to verify by actual observation that the liquid is refractive enough to show no shadow-edge in the field of view of the refractometer, or at least one near the limit of the field corresponding to the highest refractive indices.

solid substance under examination, its precise refractive index is of no consequence. To give good results the facet used in the test must be flat, and must be placed lightly on to the dense glass of the instrument, so that it is truly parallel to the plane surface of the glass; for good results, moreover, the facet must have a good polish.

It may be noted that the addition of tetraiodoethylene to the saturated liquid mentioned above raises the refractive index to 1·81. A liquid with a still higher refractive index is phenyldi-iodoarsine, which at 15° C. has an index of 1·848 for sodium light, and is a fine orange in colour; it must be used with great caution, because it is poisonous and attacks the skin as well as the glass of the refractometer, if left in contact with it too long. Other liquids have been proposed, but none on the whole is so convenient for use with refractometers as those mentioned.

We have so far assumed that the substance which we are testing is simple and gives a single shadow-edge; but, as may be seen from the table in Part IV (p. 522), many of the gemstones are doubly refractive, and such will in general show in the field of the refractometer two distinct shadow-edges, more or less widely separated. Suppose, for example, we study the effect produced by an olivine (peridot), which displays the phenomenon to a marked degree. If we revolve the stone so that the facet under observation remains parallel to the plane surface of the dense glass of the refractometer and in contact with it, we notice that both the shadow-edges in general move up or down the scale. In particular cases, depending upon the relation of the position of the facet selected to the crystal symmetry, one or both of them may remain fixed, or one may even move across the other. But whatever facet of the stone be used for the test, and however variable be the movements of the shadow-edges, the highest and lowest readings obtainable remain the same; they are the greatest and least of the principal indices of refraction, such as are stated in the table in Part IV, and their difference measures the maximum amount of double refraction possessed by the stone. The explanation of this phenomenon is discussed below (p. 89). The procedure is therefore simplicity itself; we have merely to revolve the stone on the instrument, usually through not more than a right angle, and note the greatest and least readings. It will be noticed that the shadow-edges cross the scale symmetrically in the critical, and skew-wise in intermediate positions.

Fig. 52 represents the effect when the facet is such as to give simultaneously the two readings required. The shadow-edges *a* and *b*, which are coloured in white light, correspond to the least and greatest respectively of the principal refractive indices, while the third shadow-edge, which is very faint, corresponds to the liquid used—methylene iodide. It is possible, as we shall see in a later chapter, to learn from the motion if any, of the shadow-edges something as to the character of the double refraction. Since, however, each shadow-edge is spectral in white light, they will not be distinctly separated unless the double refraction exceeds the relative colour-dispersion. Topaz, for instance, appears in white light to yield only a single shadow-edge, and may thus easily be distinguished from tourmaline, in which the double refraction is usually large enough for the separation of the two shadow-edges to be clearly discerned. In sodium light, however, no difficulty is experienced in distinguishing both the shadow-edges given by substances with small amount of double refraction, such as chrysoberyl, quartz and topaz, and a skilled observer may without difficulty detect the separation in the extreme instances of apatite, idocrase and beryl. The shadow-edge corresponding to the greater refractive index is always less distinct, because it lies in the bright portion of the field. If the stone or its facet be small, it must be moved on the plane surface of the dense glass until the greatest possible distinctness is imparted to the edge or edges. If it be moved towards the observer from the farther end, a misty shadow appears to move down the scale until the correct position is reached, when the edges spring into view.

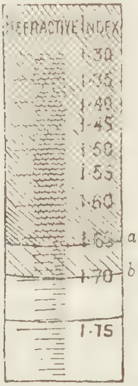
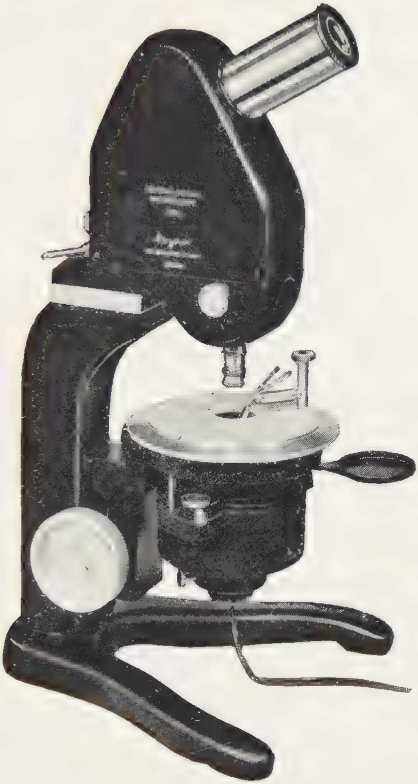


Fig. 52.—Shadow-edges given by a double-refractive substance.

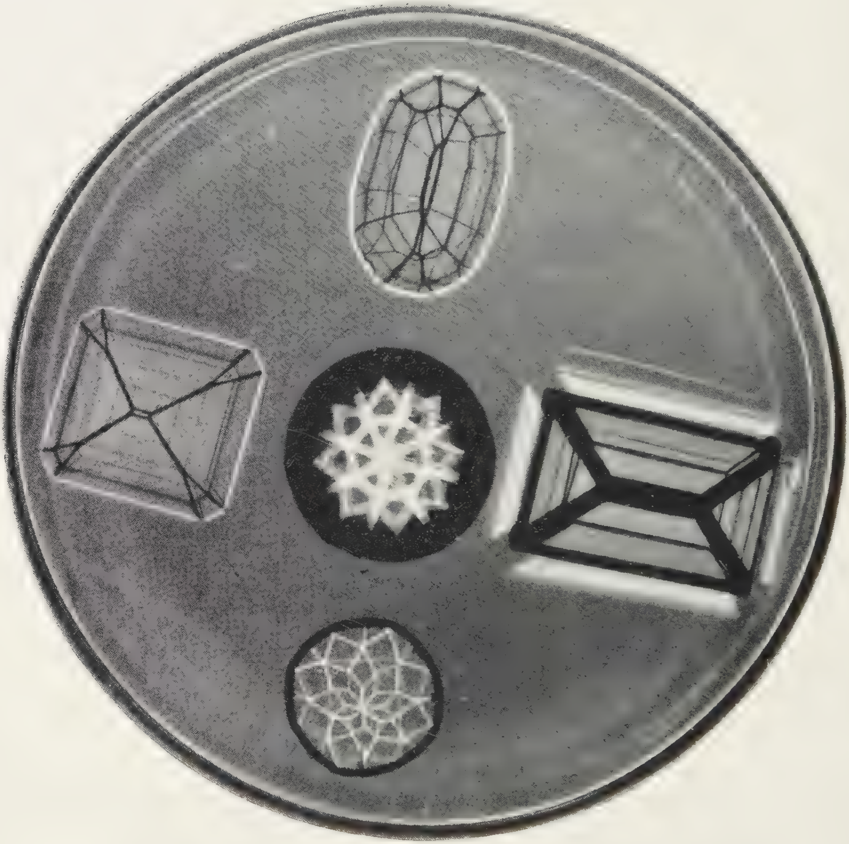
Any facet of a stone may be utilized so long as it be flat, but the table facet is the most convenient, because it is usually the largest, and it is available even when the stone is mounted. That the stone need not be removed from its setting is one of the great advantages of this method. The smaller the stone the more difficult it is to manipulate; caution especially must be exercised that it be not tilted, not only because the shadow-edge would thereby be shifted from its true position and an erroneous value of the refractive index obtained, but also because a corner or edge of the stone would inevitably scratch the glass of the instrument, which is far softer than the hard gemstones. Methylene iodide will in time attack and stain the glass, and must therefore be wiped off the instrument immediately after use.

It is a wise precaution in a doubtful case to study the effect when the stone is illuminated from above and not below. As was remarked above (p. 60), the fields become reversed, and instead of a dark one above



1. Rayner microscope. (One-third actual size)
(Reproduced by courtesy of Messrs. Rayner & Keeler Ltd., London)

2. Rayner refractometer. (Three-fifths actual size)



Pink topaz.
Step-cut kunzite. White zircon. Step-cut quartz.
Cushion-cut white sapphire.

Immersed in medium $n_D = 1{\cdot}66$. *Photo: B. W. Anderson*

III. IMMERSION CONTACT PHOTOGRAPH

with a greenish edge we have a dark one below with a reddish edge, but in either case the position of the yellow part of the spectral edge remains the same. Indeed, if there be any difference, a mistake has been made; for instance, the first shadow-edge may have been given by a facet inclined at a small angle to the one on which the test was supposed to have been made.

Other refractometers based upon the same principle have been made. The Tully instrument, devised in 1925 by B. J. Tully, was designed as a table model. The optical system was extended to give a very open scale, and the hemisphere could be rotated together with the stone under test upon it.

In the Rayner refractometer (plate II), which was introduced in 1935, the dense glass has the prismatic form which is common in refractometers designed for use with liquids, and the beam of light received from it is parallel and may be collected by a short-focus telescope of the customary pattern. The scale is divided to the second place of decimals from 1·30 to 1·87. An orange-coloured filter is provided to slip over the aperture to render the illumination less dispersive; it is not required if sodium light be employed. The eyepiece is focused by rotation, and a polarizing cap is available to facilitate observations in the case of doubly-refractive stones. A hinged shield is provided to screen unwanted light from the stone and to protect the glass when the instrument is not in use. Since the glass is fixed, stones must be revolved on it for the measurement of the least and greatest of the principal refractive indices, care being exercised not to scratch the glass.

The upper limit of the range of the instrument is extended just beyond 2·00 in a model incorporating a prism of blende in place of the dense glass. The use of diamond in place of blende, whilst offering little appreciable further extension of the upper limit, would have the advantage of providing a highly polished surface of such great hardness that it would not suffer abrasion in use.[1] A further model incorporates a prism of colourless synthetic spinel. The range is thus limited to 1·69, but in addition to its greater hardness, spinel has a much lower dispersion than that of the dense glasses, only a little higher than that of most of the gemstones which fall within the range of the instrument. Hence the shadow edges in white light are uncoloured and sharp, and accurate readings are more readily made without recourse to monochromatic light.

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[1] See B. W. Anderson, C. J. Payne and J. Pike, *Mineralogical Magazine*, 1940, vol. XXV, pp. 579–83.

Refractive index from curved surfaces

The procedure described above demands a polished plane facet on the stone under examination. Until recently it was thought that the presence of such a facet was a prerequisite to the successful use of a refractometer, but a technique first developed in America by Lester Benson enables results from a curved surface such as a polished cabochon.

A minute spot of liquid is placed between the curved surface and the glass of the refractometer, and spreads as a tiny area of contact. Instead of the eye being placed close to the eyepiece it is held at a distance of twelve or fifteen inches in the correct line of sight. The 'spot contact' can then be seen as a small circular area. When viewed against the lower part of the refractive index scale this area is dark, but, as the head is moved upwards to bring the spot over the higher readings, total reflection sets in and the spot becomes light. In the critical position it is bisected horizontally into a dark upper half and a light lower half. In order to take the corresponding reading on the scale, with the head held at this distance from the eyepiece, the eye must be re-focused; the facility with which this can be achieved varies with the individual observer. A relatively short-sighted eye is better than a long-sighted one; in some cases the wearer of spectacles is at an advantage.

Readings given by this method of 'spot contact' or 'distant vision' are not as critical as those obtained in the orthodox manner from plane surfaces, but they open up a useful additional field to the refractometer; results can be obtained not only from cabochon stones but also from minute faceted stones too tiny for the normal method.

2 TOTAL-REFLECTOMETER

Instruments for the determination of refractive indices by the measurement of the critical angle of total-reflection consist essentially of a large hemisphere of dense glass mounted upon a vertical spindle and a telescope rotatable about a horizontal axis passing accurately through the centre of the hemisphere. (In the original total-reflectometer devised by Carl Pulfrich in 1886 the dense glass was cylindrical in form; the hemispherical shape was introduced by Ernst Abbe in 1890.)

In the usual type of total-reflectometer the spindle carrying the hemisphere is rotatable about its central vertical axis, a scale being provided which reads to degrees of arc. The tube of the telescope is for convenience of observations bent through a right angle, the light being reflected by a prism, and the telescope is rigidly attached to a graduated circle, which is divided to half degrees and by means of a vernier scale may be read to minutes of arc. The circle is so divided that the angle of total-reflection may be read off either on the left or the right of the observer; since these angles must be identical, we have here a means of checking and adjusting any zero error that there may be. The telescope is fitted with alternative sets of objective and eyepiece, giving different magnifications; there is usually also a third objective which enables the stone or crystal on the plane surface of the hemisphere to be viewed. Revolving discs with openings of various diameters may be inserted in the focal plane of the telescope and eccentrically with respect to the optical axis to restrict the observations to any desired part of the stone or crystal. To facilitate the study of colour-dispersion or small amounts of double refraction the circle may be connected to a micrometer screw, fitted with drum and index.

B. IMMERSION METHOD. THE BECKE EFFECT

A transparent object can be discerned by our eyes because it differs in refraction or colour from the surrounding medium, and the greater the difference in refraction the more outstanding is the object. A colourless stone immersed in a colourless liquid with precisely the same refractive index would be quite invisible. The *immersion method* of determining refractive indices is based on this principle. It is particularly suited to the examination of such material as rounded beads, minute gemstones or fragments taken from rough or worked pieces of turquoise or jade (or their imitations), which cannot be used directly on a refractometer. The material under examination is immersed in a succession of liquids until one is found which has the same refractive index; a drop of the liquid may then be placed on a refractometer and its index measured.

In its most usual application the method is used in conjunction with a microscope. Very small fragments may be mounted on an ordinary plane microscope slide. The most convenient procedure is to scatter a few fragments on the *dry* slide, cover these with a *dry* cover slip and then place a drop of liquid on the slide against the edge of the slip. The liquid will be drawn beneath the cover slip by capillary action and will surround the fragments without displacing them or causing them to clot together. With such minute fragments it is impracticable to re-mount the same material in a further liquid, and sufficient material must be available for the number of successive mounts required. Larger fragments will call for the use of a cavity slide; still larger material, such as small cut stones, is placed in an immersion cell, used uncovered.

The magnitude of the difference between the refractivity of the liquid and the immersed solid determines the 'relief' shown by the latter—the prominence of outline, visibility of surface markings and the like. With a large difference there is a wide dark border and all surface irregularities are clearly visible; one has the impression of looking *at* the object rather than *through* it. With a close approach the outline, marked only by a thin dark line, is much less distinct and the surface is scarcely visible. The 'disappearance' of the object, however, would obviously not be a satisfactory criterion of exact agreement between the refractive indices, and use is made of a phenomenon first elucidated by F. J. Becke. When a beam of light impinges on an inclined boundary between two media of different refractivities (fig. 53), the beam is deflected towards the medium of higher refractive index. The two figures (i) and (ii) show that this is true regardless of the sense of slope of the boundary. (Becke limited his original explanation to the case of a vertical boundary and a slightly convergent incident beam. The effect has since been shown to be much more generally realized, and in fact the most sensitive conditions are usually obtained by stopping down the incident light to give a narrow parallel beam.) When the surface of the medium is accurately focused ($a - b$, fig. 53 (i)), the boundary is seen as a dark line, owing to this deflection of the light impinging on it. By raising the microscope slightly above focus ($c - d$, fig. 53 (i)) a line of extra brightness is seen where the deflected rays reinforce adjacent direct rays; as the focus is raised further, this bright line appears to move laterally into the medium of higher refractive index. The mnemonic is extremely easy; if the microscope be moved *up*, then the bright line moves *up* to the medium of *higher* refractive index. If the test be checked by moving the

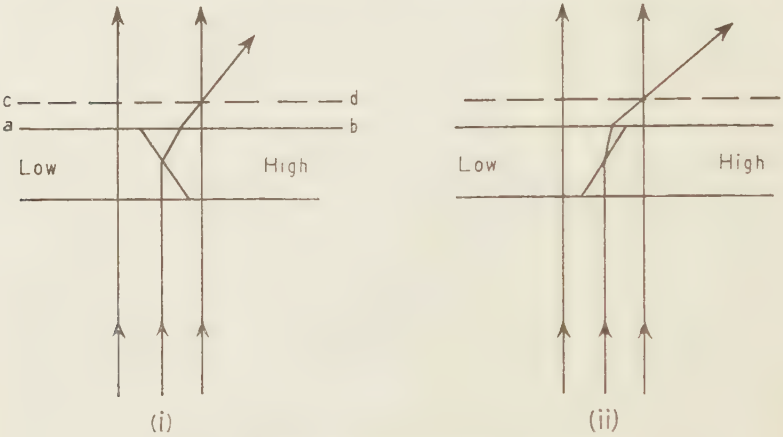

FIG. 53.—Diagram illustrating the Becke effect.

tube *down* below the position of focus, the bright line moves *down* into the medium of *lower* refractive index. If the difference of refractive indices be very considerable, light impinging on the boundary may be totally reflected (fig. 54), when a wide and completely black boundary

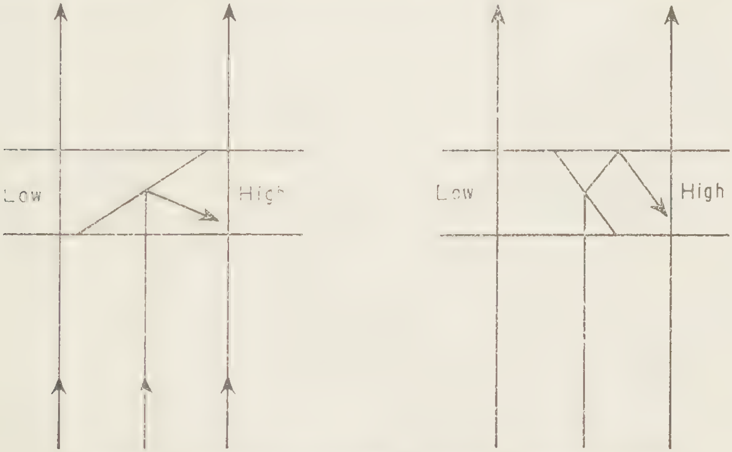

FIG. 54.—Total reflection caused by an oblique boundary.

will be seen from above. In such circumstances it may be difficult to observe any bright-line effect, and an immersion liquid of very different index should be tried at once. Since the dispersion of most of the liquid immersion media employed is greater than that of most solids, an exact match is possible only in monochromatic light; with white light, colour fringes may be visible as agreement is approached. It must be remembered also that the refractive indices of liquids vary rapidly with change of temperature, and care must be taken to see that the liquid under the microscope and the drop on the refractometer are both at about ordinary room-temperature.

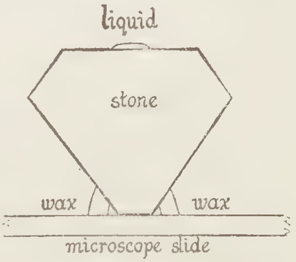

FIG. 55.—Becke effect: liquid on stone.

As a microscopic procedure for the accurate determination of refractive indices the immersion method has been highly developed by mineralogists, and we shall refer to it again (p. 122) after a discussion of double refraction. It is not limited in application, however, to microscopic objects. A large stone may be attached to a microscope slide by wax near the culet, so that the table facet is uppermost and horizontal fig. 55), and a drop of the liquid placed upon the latter facet; the effect will be seen at the edge of the drop. On a purely macroscopic scale, immersion contact photography[1] has been developed as a useful method of demonstrating and recording refractive index relationships. The gems to be examined are immersed in the appropriate liquid contained in a glass cell, and light from an overhead source (a vertical photographic enlarger provides a convenient set-up) is passed through the cell on to a sheet of printing paper or slow film beneath the cell. In these circumstances cut stones or shaped beads with a refractive index higher than the immersion liquid act in the manner of convergent lenses, concentrating the light towards their centres, so that in a positive print from the contact negative (plate III) they are surrounded by a black border. With a cut gemstone resting on its table facet, the edges between pavilion facets are marked out in white lines. If the difference of indices is very large, the effect is exaggerated by total internal reflection, as noted above, and there is a very wide black border. Stones with a refractive index lower than the liquid, on the other hand, are surrounded by a white border (corresponding to the action of a divergent lens), and the edges are marked in black lines. When drawing quantitative deductions from such photographs, however, it is essential to bear in mind that the photographic emulsion will be most sensitive to the shortest wave-lengths in the incident illumination, and for these wavelengths the refractive index of the liquid will be appreciably higher than for the middle of the visible spectrum. In plate III the immersion liquid was α-monobromonaphthalene, for which the index in sodium light at 15° C. is 1·655, but the spodumene shows by its narrow white border the behaviour of an object with a refractive index slightly lower than that of the liquid.

In practice it is desirable to have at hand a series of liquids providing a range of refractive indices for the most convenient application of the Becke-effect method. A suitable choice may be made from the following list, the indices quoted being those corresponding to sodium light at 15° C.: water, 1·333; chloroform, 1·447; olive oil, 1·470; benzol, 1·501; cedarwood oil, 1·505; clove oil, 1·544; nitrobenzene, 1·552; monobromobenzene, 1·561; bromoform, 1·590; cinnamon oil, 1·605; monoiodobenzene, 1·619; α-monochlornaphthalene, 1·635; α-monobromonaphthalene, 1·655; methylene iodide, 1·742. By mixing the last two in equal volumes a liquid with index 1·700 is obtained. Instead of the use of different liquids, any desired gradation of refractive index up to 1·742 may be effected by mixing methylene iodide with benzol, but

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[1] B. W. Anderson, *Journal of Gemmology*, 1952, vol. III, pp. 219–25; ibid. 1956, vol. V, pp. 297–306.

owing to the volatility of the latter the refractive indices of the mixtures need checking before use; higher indices up to 1·785 may be realized by mixing methylene iodide with sulphur and up to 1·81 by adding tetraiodoethylene also.

C. MINIMUM DEVIATION

If the stone be too highly refractive for a measurement of its refraction to be possible with a refractometer and it be desired to measure its refractive indices with some degree of accuracy, recourse must be had to the prismatic method. For this purpose we must use a goniometer (p. 39), of the more elaborate type, in which the divided circle carrying the crystal-holder and the telescope may be turned independently about the same vertical axis.

The instrument consists essentially of a fixed collimator and a movable telescope; the optical axes of both of them are horizontal and intersect in the vertical axis, about which the divided horizontal circle may turn. At the focus is a slit defined by two convex circular arcs, which, when reflected by a crystal face or a stone facet in the proper position, is seen in the focal plane of the telescope by means of an eyepiece, which is fitted with a pair of cross-wires.

The stone or crystal is attached by means of a wax, which can be softened by the heat of the fingers, to the holder, which is itself clamped to the adjustment fitting, consisting of two circular arcs mutually at right angles, which are operated by tangent screws. One facet is set as nearly vertical as possible and at right angles to one circular arc, by means of which it is accurately set. It will be scarcely, if at all, affected in relative position by a movement of the other circular arc, which is used to adjust the second facet. Two horizontal adjustments in directions at right angles to each other are provided to set the stone on the turning axis of the divided circle. When both facets are accurately set so that their common edge, real or imaginary, coincides with the turning axis mentioned, the images obtained by reflection from them will cross the field in turn on rotation of the divided circle. The difference of the corresponding readings, when the images are central, gives the angle between the facets, called *A* below. For measuring this angle, the telescope is set nearly at right angles to the collimator. When it comes to the study of the light that has traversed the prism formed by the two facets, the divided circle is clamped in such a position that it reads zero when the telescope and collimator directly face each other. Both the crystal-holder fitting and the telescope are now released, and can be rotated about the central vertical axis.

It is obviously convenient to select as one of the pair of facets the table facet; the second facet will then be one of the larger facets on the under side of the stone. If now the light from the collimator falls upon the table facet and the telescope is turned to the proper position to receive the emergent beam after it has traversed the prism formed by the two facets, a spectral image of the object-slit, or, in the case of a doubly-refractive stone, two spectral images will in general be seen in white light; in sodium light the images will be sharp and distinct. Suppose that we rotate the stone in the direction of diminishing deviation and simultaneously the telescope so as to retain the image in the field of view, we find that the image moves up to a certain position and no farther, whichever way the stone be turned; this therefore is the position of minimum deviation.

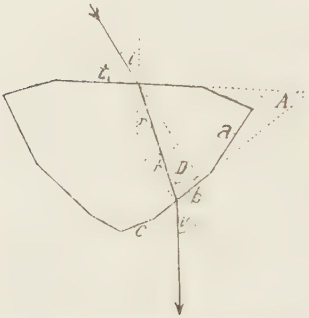

FIG. 56.—Minimum deviation of light traversing a faceted stone.

The question at once suggests itself, what are the angles of incidence and refraction of the beam of light in these special circumstances. For simplicity we shall assume the stone to be singly refractive. Fig. 56 represents a section of a step-cut stone, perpendicular to a series of facets with parallel edges; *t* is the table facet, and *a*, *b*, *c* are facets on the under (culet) side. The path of a beam of light traversing the prism formed by the pair of facets, *t* and *b*, is shown. Suppose that *A* be the interior angle of the prism (it is the angle between the normals to the facets), *i* the angle of incidence at the first facet and i' the angle of emergence at the second facet, and *r* and r' the angles of refraction within the stone at the two facets respectively, then at the first facet the light has been bent through the angle $i-r$, and at the second facet through an angle $i'-r'$, and the angle of deviation, *D*, is therefore given by the equation: $D = i + i' - (r + r')$. We find further that $r + r' = A$, whence it follows that $A + D = i + i'$.

Now a path of light is clearly reversible; that is to say, if a beam of light traverses the prism in the path shown from the facet *t* to the facet *b*, it can take precisely the same path in the reverse direction. Since we find by experiment that there is only one position of minimum deviation, we can deduce from this fact that the conditions at the two facets will be the same, and consequently the angles *r* and r', and therefore also *i* and i', will be equal. This equality may be established by stricter reasoning. From Snell's law we have the relations, n being the refractive index of the stone

$$\sin i = n \sin r, \ \sin i' = n \sin r'$$

Taking di, di', dr, dr' as small variations, we have at the critical value, when D is constant,

$\cos i \,.\, di = n \cos r \,.\, dr$; $\cos i' \,.\, di' = n \cos r' \,.\, dr'$; $dr + dr' = 0$; $di + di' = 0$; and find on elimination $\sin^2 r = \sin^2 r'$, and $r = r'$; or $\sin^2 i = \sin^2 i'$, and $i = i'$.

Therefore at minimum deviation we have $r = \frac{1}{2}A$ and $i = \frac{1}{2}(A + D)$, and from the equation above

$$n = \sin \tfrac{1}{2}(A + D)/\sin \tfrac{1}{2}A$$

If the stone be not singly refractive, as we assumed, two images may be seen and two sets of measurements must be carried out, each image in turn being set to a position of minimum deviation. The true significance of the values then calculated is considered later (p. 92), after a discussion of double refraction in crystals. We can accept for the present that the values are sufficiently accurate for discriminative purposes even with doubly refractive stones.

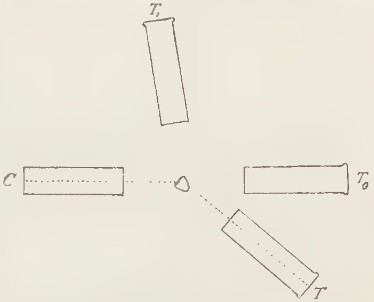

FIG. 57.—Course of observations in the method of minimum deviation.

It may be noted that in the case of a brilliant-cut diamond no light should emerge from the under side of the stone. In general, the angle, A, between the two facets must not be too large, because otherwise the beam of light will be totally reflected at the second facet; on the other hand, it should not be too small, because any error in its determination will seriously affect the accuracy of the value calculated for the refractive index. Although sodium light is essential for precise work, sufficiently accurate values for discriminative purposes are obtainable by noting the position of the yellow part of the spectral images given in white light.

In the case of a stone such as that depicted in fig. 56, images are given by other pairs of facets, for instance *ta* and *tc*, unless the angle included by the former be too large. There might therefore be some doubt as to which pair some particular image corresponded; but no confusion can arise if the following procedure be adopted.

The table, or some easily recognizable facet, is selected as the facet at which light enters the stone. The telescope is first placed in the position in which it is directly opposite the collimator (T_0 in fig. 57), and clamped. The scale is turned until it reads exactly zero, 0° or 360°, and clamped. The telescope is released and revolved in the direction of increasing readings of the scale to the position of minimum deviation,

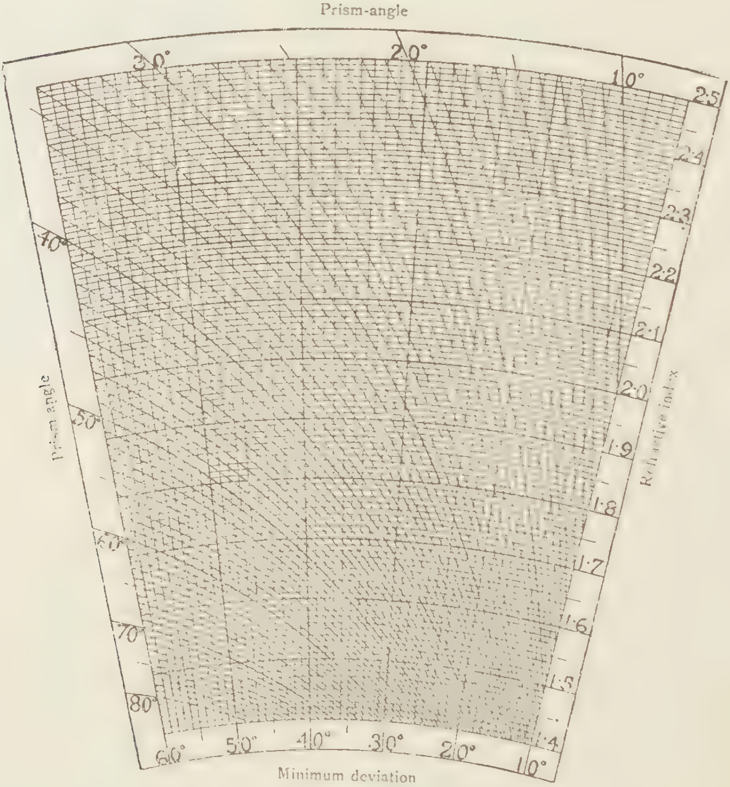

FIG. 58.—Refractive index diagram.

T; the reading of the scale gives at once the angle of minimum deviation, *D*. The holder carrying the stone is now clamped to the scale, and the telescope is turned to the position, T_1, in which the image given by reflection from the table facet is in the centre of the field of view; the reading of the scale is taken. The telescope is clamped, and the scale is released and rotated until it reads the angle already found for *D*. If no mistake has been made, the reflected image from the second facet is now in the field of view. It will probably not be quite central, as theoretically it should be, because the stone may not have been originally quite in the position of minimum deviation, a comparatively large rotation of the stone producing no apparent change in the position of the refracted image at minimum deviation, and also, because, as has already been stated, the method calls for further discussion in its strict application to some types of doubly refractive stones. The difference in readings, however, should not exceed 2′. The reading, *S*, of the scale is now taken, and it together with 180° subtracted from the reading for the first facet, and the value of *A*, the interior angle between the two facets, obtained.

Let us take an example (a garnet)—

Reading $T (= D)$	40°	41′	Reading T_1	261°	35′
			less 180°	180	0
				81	35
			Reading S	41	30
$\frac{1}{2}D$	20	20½	A	40	5
$\frac{1}{2}A$	20	2½	$\frac{1}{2}A$	20	2½
$\frac{1}{2}(A + D)$	40	23			

$n = 1{\cdot}8906$

The readings *S* and *T* are very nearly the same, and therefore we may be sure that no mistake has been made in the selection of the facets.

In place of logarithm-tables we may make use of the diagram[1] shown in fig. 58. The radial lines correspond to the angles of minimum deviation and the skew lines to the prism angles, and the distance along the radial lines gives the refractive index. We run our eye along the line for the observed angle of minimum deviation and note where it meets the curve for the observed prism angle; the refractive index corresponding to the point of intersection is at once read off.

The refractive indices of the gemstones are listed in the table in Part IV (p. 520).

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[1] The diagram was devised and drawn by the author, and described by him in the *Mineralogical Magazine*, 1906, vol. XIV, pp. 192–3.

V

LUSTRE AND SHEEN

It has been stated in an earlier chapter that, whenever light in one medium falls upon the surface separating it from another medium, some of the light is reflected within the first, while the remainder passes out of it by refraction into the second medium, except when the latter is of greater refractivity and the angle of incidence exceeds that corresponding to total-reflection. In the case of a cut stone viewed in air, some of the light is always reflected, while the remainder passes into the stone. The ratio of the amount of the reflected to that of the refracted light depends partly upon the angle of incidence, but mainly upon the nature of the stone—its refractivity and the character of the surface—and determines the lustre; the greater the relative amount of light reflected, the more lustrous does the stone appear to be.

We may distinguish five different kinds of lustre; the intensity of each depends upon the polish of the surface. From a dull or matt, that is, an uneven, surface the incident light is scattered in many directions on reflection, and in no direction is the reflection brilliant. All gemstones take a good polish, and have therefore, so long as the surface retains its polish and is kept clean, considerable brilliancy; such material as turquoise cannot, because of its softness, take a really good polish, and is consequently always comparatively dull.

The different kinds of lustre are:

(1) Adamantine, characteristic of diamonds.
(2) Vitreous, as seen on the surface of fractured glass.
(3) Resinous, as shown by the resins; and greasy.
(4) Pearly, as seen on the surface of pearls. It is usually shown by cleavage faces of crystals.
(5) Silky, as shown by fibrous minerals.

Not many gemstones have sufficiently high refractivity to display an adamantine lustre. Cassiterite (tinstone) is occasionally found in pieces large and clear enough for cutting, and such stones possess a lustre challenging that of diamond. The lustre of gemstones, the refractivity of which approaches that of diamond, such as zircon, sphene, garnet and corundum, is intermediate between the adamantine and the vitreous. A typical example of the latter lustre is provided by quartz. Most gemstones have a vitreous lustre, though it varies in degree, the harder and the more refractive species being on the whole the more lustrous.

Certain optical effects which may be grouped under the general term, sheen, are due to the reflection of light from inclusions within the stone. Some specimens of corundum, when viewed in the direction of the principal crystallographic axis, display six narrow bands of light radiating from a centre, or, as it may alternatively be expressed, three such bands crossing, the angles between them being 60°, in a manner suggestive of the conventional representation of stars. Such stones are consequently known as asterias or star-stones—star-rubies or star-sapphires, as the case may be—and this phenomenon is termed asterism. Its cause may be traced to a regular arrangement of bundles of lines within the structure, which are at right angles to the principal crystallographic axis and are severally inclined to one another at angles of 60°. The lines may be composed of included needles of rutile, tubular cavities or even colloidal particles. The tendency to conform to this hexagonal arrangement is linked up with the lamellar twinning characteristic of corundum. For the best effect star-rubies and star-sapphires should be rather steeply cabochon-cut with the base at right angles to the principal crystallographic axis; otherwise the centre of the star will not appear at the top of the stone.

Asterism is commonest and best known in corundum, but other gemstones do occasionally display the phenomenon. The form of the star obviously must be immediately related to the crystal symmetry. In certain garnets, which possess the linear structure suitable for asterism, since the crystal symmetry is cubic, the star is formed of two bands of light crossing at right angles; there are three directions, mutually at right angles, in which such stars are visible, and, if each arm could be followed round, it would be found, in directions perpendicular to octahedron faces on the crystal, to cross two other arms at angles of 120° (or 60°). In some garnets the fibres run parallel to the edges of the rhombic dodecahedron; consequently four-rayed stars are visible in six directions. Both green zircon and aquamarine occasionally show asterism owing to the regular arrangement of inclusions perpendicular to the principal crystallographic axis. Rose-quartz, too, frequently shows a six-rayed star. Asterism is produced in some synthetic corundums and spinels by engraving three sets of fine lines on the base of a cabochon, which is set with a metallic backing.

The cat's-eye effect known as chatoyancy has a similar cause, but in this instance the bundles of lines are parallel to a single direction, and, if the stone be viewed at right angles to this direction, a band of light is visible running across the bundle; the finer the lines the sharper is the band of light. Cat's-eyes should therefore be cut in a shallow cabochon, the base being parallel to the direction of the bundle. The lines may consist of microscopic channels, fibres or colloidal particles. The true cat's-eye is a variety of chrysoberyl, in which a multitude of microscopic channels runs parallel to one of the principal axes, but the term has also been applied to quartz, showing a similar appearance, which is really a silicified form of a fibrous mineral, such as asbestos. Star-stones and cat's-eyes only display their full beauty when viewed by light emanating from a single source of light, such as the sun or an electric lamp.

Closely allied to cat's-eye are tiger's-eye and hawk's-eye. Both come from South Africa and both are silicified crocidolite, but in the former the original blue colour has been converted by oxidation into a golden yellow, while in the latter the original colour has remained with little or no alteration.

Chatoyancy is not restricted to chrysoberyl and quartz. Any translucent mineral, which is sufficiently fibrous in structure, will, if suitably cut, show chatoyancy. Thus, tourmalines with an effective cat's-eye effect are known and sapphires can be cut so that only one arm of the star is visible and a cat's-eye effect is thus produced. Beryl, apatite, diopside and both pink and violet scapolite also sometimes display chatoyancy.

The inclusions responsible for the effects which have been considered so far are microscopic or even sub-microscopic in size. Others sometimes occur, which are larger and more widely spaced. If they run parallel to the same direction and light be viewed in a plane at right angles to it a flash will be seen. These inclusions are called silk, because the effect resembles that given by that fabric. Corundum often shows silk, due to the inclusion of rutile needles.

In some minerals the ordinary kind of lustre may be blended with the optical effect due to interference or diffraction. The pearly lustre (p. 76), which is the typical example of this optical effect, may be presented by cleavage faces, for instance in topaz, due to the development of cracks near the surface, but would be visible in a cut stone only if flaws were to develop; incipient cleavage cracks in a cut stone are termed feathers.

The lovely blue sheen, or schiller, which is such an attractive feature of moonstone arises from the interference of light at the minutely thin lamellae of soda-lime feldspar (albite or oligoclase) and potash-lime feldspar (orthoclase or microcline), which alternate in the same crystal. The property disappears on heating to a high temperature.[1]

The iridescence due to the interference of light is shown at its best by opal. The wonderful effect which is the glory of this gemstone is therefore often termed opalescence. Scientifically there is much to be said for describing the colour effect as iridescence and restricting the term opalescence to the milky or pearly reflection shown by common opal and occasionally by some other gems such as moonstone. In common parlance, however, this distinction has not been maintained—the Shorter Oxford English Dictionary defines opalescence as 'exhibiting a play of colours or iridescence like that of opal'. The effect arises from the form of structure which is characteristic of this species. Opal is not a crystal but a solidified jelly containing a variable amount of water; on cooling it often became permeated with extremely thin films which differ slightly in their refractivity. At the surface of each film interference of light takes place just as at the surface of a soap-bubble, and the more evenly the films are spaced apart the greater the uniformity of the colour displayed; the actual tint depends upon the thickness of the films. In the case of clear, translucent pieces the tint of the transmitted light is complementary to the tint of the reflected light. Some opal does not display iridescence until it has been immersed in water, because it is fissured with cracks, which contain merely air, and light normally is totally reflected from their hither surfaces. When, however, the cracks are filled with water, they are rendered translucent, and, if they be thin enough, interference of light will result. Such opal is known as hydrophane (p. 378).

It was formerly supposed that, as the jelly formed, it became fissured with cracks, which subsequently were filled with similar material with a different water content and therefore different refractivity, and these cracks thus filled were the films causing the iridescence. This explanation is plausible, but the existence of such cracks has never been proved. Some opal appears to be[2] the result of the replacement of calcite crystals, usually simple rhombohedra, which are characterized by an ultramicroscopic twin-lamellar structure, by a silicic acid jelly.

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[1] The interested reader, desirous of studying more fully this property of moonstone, should consult the memoir by Edmondson Spencer, 'A contribution to a study of moonstone from Ceylon and other areas and of the stability-relations of the alkali-felspars,' *Mineralogical Magazine*, 1930, vol. XXII, pp. 291–567.

[2] E. Baier, 'Die Optik der Edelopale,' *Zeitschrift für Kristallographie*, 1932, vol. 81, pp. 183–218.

This complex laminated structure has survived the pseudomorphosis, and these minutely thin laminae act on light falling upon them in the same manner as thin liquid films. X-ray studies of opal have revealed rather surprisingly that some of the silica present has a structural arrangement corresponding to certain types of tridymite and cristobalite (p. 369), polymorphs of silica with stability fields at high temperatures. Interstratification of layers with these different arrangements may be one way in which structures may develop giving rise to iridescence.

VI

DOUBLE REFRACTION

The optical phenomena presented by many gemstones are complicated by their property of splitting up a beam of light into two with, in general, differing characters. In this chapter we shall discuss the nature of double refraction, as it is termed, and methods for its detection. The phenomenon is not one that comes within the purview of everyday experience.

So long ago as 1669 a Danish physician, by name Bartholinus, noticed that a plate of the transparent mineral, which at that time had recently been brought over from Iceland, and was therefore called Iceland-spar, possessed the remarkable property of giving a double image of objects close to it, when viewed through it. Subsequent investigation has shown that much crystallized matter is doubly refractive, but in calcite—to use the scientific name for the species which includes Iceland-spar—alone among common minerals is the phenomenon so conspicuous as to be obvious to the unaided eye. The apparent separation of the pair of images given by a plate cut or cleaved in any direction depends upon its thickness. The large mass, upwards of two feet (60 cm.) in thickness, which is exhibited at the far end of the Mineral Gallery of the British Museum (Natural History), displays the separation to a degree that is probably unique.

Although none of the gemstones can emulate calcite in this character, yet the double refraction of certain of them is large enough to be detected without much difficulty. In the case of facceted stones the opposite edges should be viewed through the table facet, and any signs of doubling noted. The double refraction of sphene is so large, namely, 0·120, that the doubling of the edges is evident to the unaided eye. In olivine (fig. 59), zircon (high) and epidote the apparent separation of the edges is easily discerned with the assistance of an ordinary lens. A keen eye can detect the phenomenon even in the case of such substances as quartz with small double refraction. It must, however, be remembered that in all such stones the refraction is single in certain directions, and the amount of double refraction varies therefore with the direction from nil to the maximum possessed by the stone. Experiment with a plate of Iceland-spar shows that the rays transmitted by it have properties differing from those of ordinary light. On superposing a second plate, we notice that there are now two pairs of images, which are in general no longer of equal brightness, as was the case before. If the second plate be rotated with respect to the first, two images, one of each pair, disappear, and then the other two, the plate having turned through a right angle between the two positions of extinction; midway between these positions the images are all equally bright. This variation of intensity implies that each of the rays emerging from the first plate has acquired a one-sided character, or, as it is usually expressed, has become plane-polarized, or, shortly, polarized.

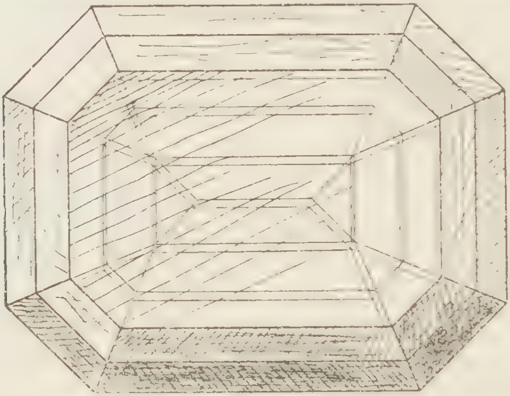

FIG. 59.—Apparent doubling of the edges of an olivine (peridot), when viewed through the table facet.

Before the discovery of the phenomenon of double refraction the foundation of the modern theory of light had been laid by the genius of Christian Huygens in the seventeenth century. According to this theory light is the result of a wave-motion (fig. 60) in the ether, a medium that pervades the whole of space whether occupied by matter or not, and transmits the wave-motion at a rate varying with the matter with which it happens to coincide. Such a medium has been assumed because it explains the phenomena of light, but it has no real existence. The wave-motion is similar to that observed on the surface of still water when disturbed by a stone flung into it. The waves spread out from the source of disturbance; but, although the waves seem to advance, the actual particles of water merely move up and down, and have no motion at all in the direction in which the waves are moving. If we imagine similar motion to take place in any plane and not only the horizontal, we form some idea of the nature of ordinary light. But after passing through a plate of Iceland-spar, light no longer vibrates in all directions, but in each beam the vibrations are parallel to a particular plane, the two planes being at right angles. The waves for different colours differ in their length, that is in the distance, 2 *bb* (fig. 60), from crest to crest, while the velocity, which remains the same for the same medium, is proportional to the wave-length. The intensity of the light varies as the square of the amplitude of the wave, that is the height, *ab*, of the crest from the mean level.

FIG. 60.—Wave-motion.

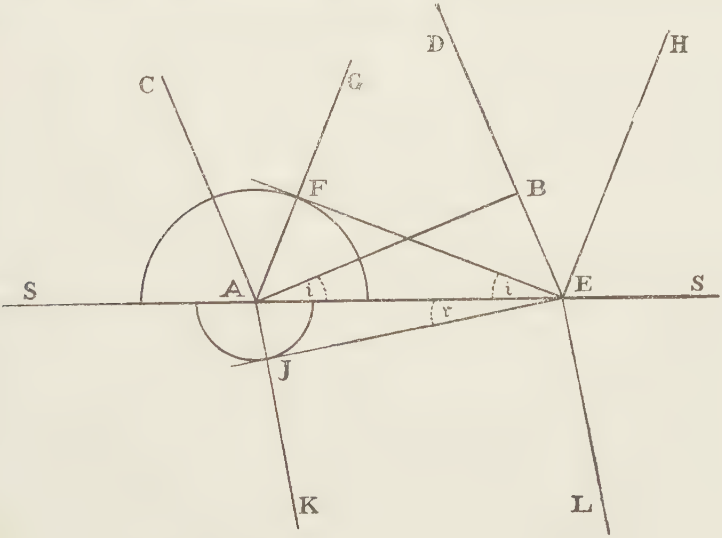

FIG. 61.—Reflection and refraction of a wave.

Let us now consider what happens to a wave when it impinges upon the plane surface separating the medium in which it is moving from a second medium. Fig. 61 represents a section, *SS*, of the surface and the wave-front, of which *AB* is a part. *AC* and *BD* are the wave-normals at *A* and *B*, and *DB* is prolonged to meet the surface in *E*. Then *BAE* is the angle of incidence, *i*. After the wave-front impinges upon the surface at *A* it will continue to move, and after an interval, depending on the velocity, v, in the first medium, the part at B will meet the surface at E. BE is therefore proportional to v, and since it is possible to select the position of B so that BE is traversed in the unit of time, then $BE = v$. While the wave-front has moved from B to E, the reflected wave-front will have moved from A to F, where $AF = v = BE$, and FE is the reflected wave-front. Its position is therefore given by the tangent from E to a circle about A with radius v. AF is prolonged to G, and EH is normal to EF. Since the triangles AFE and ABE are identically equal, the angle of reflection, FEA, is equal to the angle of incidence, BAE.

Let v' be the velocity in the second medium. Then, while B has moved to E, A will have moved in the second medium to a point, J, so that $AJ = v'$, and the new wave-front is given by the tangent, EJ, to a circle about A with radius v'. AJ, prolonged to K, is the wave-normal, and the parallel line, EL, is the corresponding wave-normal at E. Then AEJ is the angle of refraction. Now $AF = AE \sin i$ and $AJ = AE \sin r$, and hence $v' \sin i = v \sin r$, or, since $vn = v'n'$, $n \sin i = n' \sin r$ which is Snell's law (p. 52).

On refraction into a crystal of other than cubic symmetry, an unpolarized beam splits in general, as described above for Iceland-spar, into two rays, each of which is plane-polarized. By careful observation it can be shown that in Iceland-spar one of the two rays obeys Snell's law; the angles of incidence and refraction are related by a constant refractive index which is independent of the direction of travel of the ray through the crystal structure. In view of this behaviour this ray is termed the *ordinary ray* and its constant refractive index is given the symbol ω (omega). The other ray is *extraordinary* in its behaviour; its velocity varies with the direction of travel through the crystal structure so that its refractive index varies from equality with ω to a limiting value ϵ (epsilon) which, in different substances, may be either greater or less than ω. In quartz, for example, $\omega = 1{\cdot}544$, $\epsilon = 1{\cdot}553$ for sodium light; in calcite $\omega = 1{\cdot}658$, $\epsilon = 1{\cdot}486$. Crystals in which the ordinary ray is the fastest disturbance which can travel through them are termed optically *positive* (e.g. quartz), whilst those such as calcite, in which the ordinary ray is slow, are *negative*. (The mnemonic POOF may help to fix in mind the relationship between positive, ordinary and fast.)

This kind of optical behaviour is characteristic only of substances crystallizing in the tetragonal, hexagonal and trigonal systems. It is found, moreover, that in such substances there is one direction (parallel to the principal axis of symmetry) parallel to which light will travel with no double refraction. Such a direction is an *optic axis*; crystals belonging to these systems are optically *uniaxial*. When light travels parallel to the optic axis it is propagated with a velocity $1/\omega$ by vibrations executed at right angles to the optic axis; when it travels through the crystal in any other direction the *velocity depends upon the direction of vibration utilized.* If the vibrations are still executed at right angles to the optic axis direction the velocity is still $1/\omega$ and the disturbance travels as an ordinary ray; if, however, the vibrations take place in a plane through the optic axis (a principal plane) the disturbance travels as an extraordinary ray with a velocity $1/\epsilon'$, where ϵ' is a value of the extraordinary refractive index intermediate between ω and the limiting value ϵ. This limiting value is reached when the disturbance travels at right angles to the optic axis direction, propagated by vibrations parallel to that direction. Thus if we suppose light to spread outwards from a point within a uniaxial crystal the ordinary ray will have reached, after a unit of time, the surface of a sphere of radius $1/\omega$; the extraordinary will have reached the surface of a figure which is found to be an ellipsoid of revolution, with semi-axes $1/\epsilon$, $1/\epsilon$ and $1/\omega$ (fig. 62). These two surfaces together constitute the *uniaxial ray-surface.* In a positive crystal the spherical portion encloses the ellipsoid, since the ordinary ray always travels faster than the extraordinary; in a negative crystal the ellipsoid encloses the sphere.

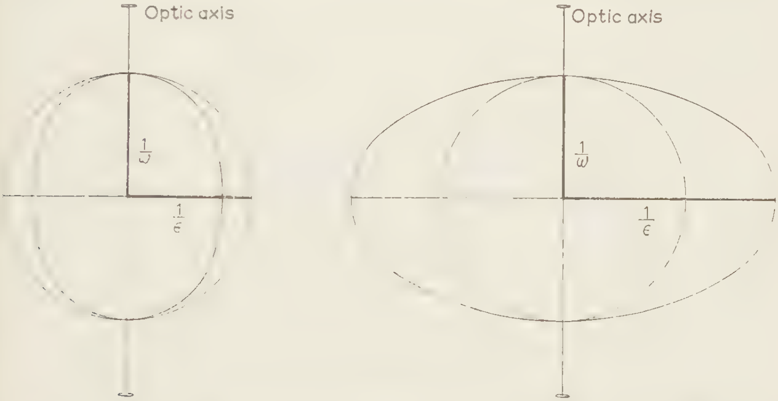

FIG. 62.—Sections of the ray-surface of a positive and of a negative uniaxial crystal.

The fact that the extraordinary ray-front is ellipsoidal introduces a complication into the optical study of doubly refracting substances which is not encountered whilst observations are restricted to singly refracting media. On the wave theory the velocity of a wave-front is inversely proportional to the refractive index of the medium in which it is travelling, and this velocity is measured along the wave-normal. With spherical ray-fronts the wave-normal coincides with the ray-direction, so that wave- and ray-velocities are identical, but with an ellipsoidal ray-front (fig. 63) the wave-normal does not coincide with the ray-direction except when this lies along, or at right angles to, the optic axis.

To circumvent these difficulties various diagrammatic devices have been introduced into crystal optics, and the most useful is the figure known as the Fletcher Indicatrix.[1] The uniaxial indicatrix is an ellipsoid of revolution constructed on axes *directly proportional to* the values of refractive indices ω, ω, ϵ (fig. 64). Since it is used to represent diagrammatically the optical properties of the crystal it must be pictured as located within the crystal in conformity with the symmetry; the axis of rotational symmetry of the ellipsoid coincides with the unique symmetry axis of the crystal (fig. 65). It must be clearly understood, however, that this particular surface has a diagrammatic significance only and does not represent anything real, such as the extraordinary portion of the ray-surface. Its use is to give full quantitative information about the refractive properties of any section of the crystal. If, for example, a basal section is cut from the crystal (at right angles to the optic axis) the corresponding central section of the indicatrix is a circle of radius ω,

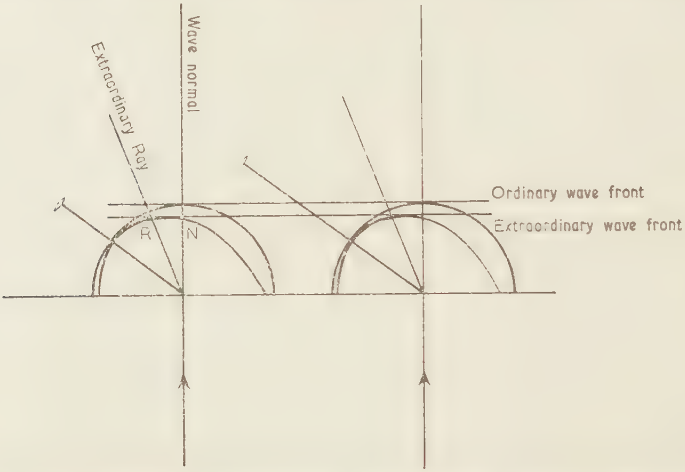

FIG. 63.—Diagram to demonstrate the difference between wave- and ray-velocity in a doubly-refracting medium.

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[1] Sir Lazarus Fletcher, 'The optical indicatrix and the transmission of light in crystals,' *Mineralogical Magazine*, 1891, vol. IX, pp. 278–388.

indicating that such a section of the crystal is singly refracting and that light is transmitted normally through it as a single unpolarized ordinary disturbance. A section of the crystal in any other direction will yield an elliptical trace of the indicatrix, indicating that all such sections are doubly refracting. The major and minor semi-axes of the elliptical trace give the refractive indices and vibration-directions of the two waves propagated normal to the section.

The use of the indicatrix can be extended to give a reasonably simple description of the optical properties of the remaining group of crystals, those belonging to the orthorhombic, monoclinic and triclinic systems. The situation here is rather more complex, there being no ordinary ray. A single incident beam gives rise, in general, to two plane-polarized refracted beams, as in uniaxial crystals, but each of these travels with a velocity varying with direction in the crystal structure. The two refractive indices, in any given instance, lie between two limiting values for the substance, α (alpha), the least refractive index, and γ (gamma), the greatest. The vibration-directions for these two extremes lie always at right-angles, and the indicatrix is an ellipsoid constructed on three *unequal* axes *OX*, *OY*, *OZ* (fig. 66), where *OX* and *OZ* are proportional

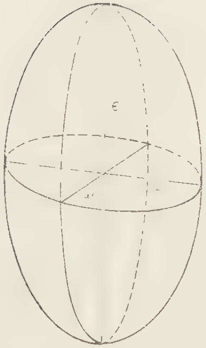

FIG. 64.—Indicatrix for a positive uniaxial crystal.

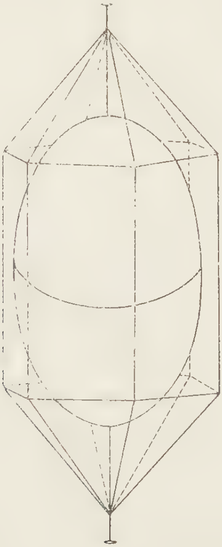

FIG. 65.—Diagram of the indicatrix correctly orientated inside a crystal of quartz.

to α and γ respectively and OY to β (beta), the intermediate value appropriate for vibrations taking place normal to the plane XOZ. As before, sections of the indicatrix afford information about the double refraction of corresponding crystal sections. There is no principal circular section, but there are two circular sections (fig. 67) of radius β, intersecting in OY and equally inclined about OX (and OZ). These indicate that there are now *two* directions in the crystal, normal to these circular sections, parallel to which light is propagated without double refraction. The acute angle between the two normals is the optic axial angle $2V$; crystals belonging to these systems are thus optically biaxial. This is the third of the three categories in which all crystals are grouped according to the nature of their optical properties:

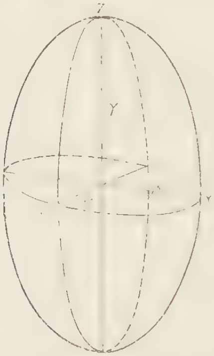

FIG. 66.—Indicatrix for a biaxial crystal.

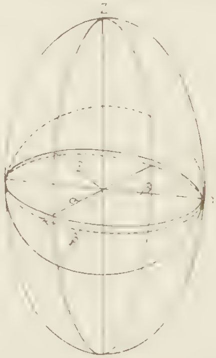

FIG. 67.—Circular sections of a biaxial indicatrix.

Isotropic (Isoaxial)	Uniaxial	Biaxial
	Tetragonal	Orthorhombic
Cubic	Hexagonal	Monoclinic
	Trigonal	Triclinic

A distinction of sign is made also in biaxial crystals, by analogy with that in uniaxial crystals. If $\beta \rightarrow \alpha$, in the limit $OY = OX$ and the indicatrix becomes an ellipsoid of revolution corresponding to a positive uniaxial crystal, whereas if $\beta \rightarrow \gamma$ the limiting case, with $OY = OZ$, is that of a negative uniaxial crystal. Hence biaxial crystals for which $(\gamma - \beta) > (\beta - \alpha)$ are termed positive, those for which $(\gamma - \beta) < (\beta - \alpha)$ negative. Typical values for topaz are: $\alpha = 1{\cdot}630, \beta = 1{\cdot}631, \gamma = 1{\cdot}638$ (optically positive); for epidote, $\alpha = 1{\cdot}733, \beta = 1{\cdot}755, \gamma = 1{\cdot}768$ (optically negative). The sign of the double refraction of gemstones is given in the table in Part IV (p. 522).

The biaxial indicatrix must, of course, be situated within the crystal in conformity with the crystal symmetry, but with the lower symmetry of these systems there is less restriction than in the uniaxial group. The indicatrix itself has orthorhombic symmetry, with three digonal axes in the directions *OX*, *OY*, *OZ*, at the intersections of three planes of symmetry. In orthorhombic crystals these three axes must be parallel to the three crystallographic axes *a*, *b*, *c*, though not necessarily each to each. The optic axes, equally inclined on either side of one of the digonal axes, will not (unless by chance) be normal to crystal faces. In monoclinic crystals the only symmetry requirement is that the *b* crystallographic axis should coincide with one of the axes *OX*, *OY*, *OZ*, whilst in a triclinic crystal the orientation of the indicatrix is unrestricted by any symmetry requirement.

We can now explain more fully what happens when a stone is placed on a refractometer (p. 63). As the stone is rotated on the instrument, the limiting critical *direction of travel* within the facet lies always at right angles to the normal to the facet. Hence the range of *refractive indices* traced out by the moving shadow-edges corresponds to the range in shape of the family of central sections of the indicatrix passing through the normal to the facet. A few examples will serve to make this statement clear. Beginning with a uniaxial crystal, let us suppose that the table facet is cut parallel to a principal plane, thus containing the optic axis direction (as may well be the case, for example, in tourmaline). The family of central sections passing through the normal *ON* (fig. 68) ranges from a circle of radius ω (when the light is travelling parallel to the optic axis) to an ellipse of semi-axes ω and ϵ, passing through intermediate values of ϵ'. Hence one shadow-edge remains stationary at the reading for ω, whilst the other moves gradually from this reading to the extreme value for ϵ and back again to coincidence. Since the moving shadow-edge must correspond to the extraordinary ray, the optic sign as well as the true double refraction is determined.

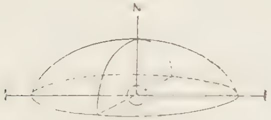

FIG. 68.—Application of the indicatrix to refractometry using a principal plane of a uniaxial crystal.

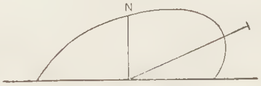

FIG. 69.—Uniaxial indicatrix when using an oblique facet.

In general, however, the facet placed in contact with the refractometer is likely to correspond to a purely random section of the indicatrix. In such a random section (fig. 69) the light will at no time during rotation of the stone *travel* parallel to the optic axis, so that two shadow-edges will be seen all the time. When the light is travelling in the plane of the diagram (fig. 69), the edges will correspond to ω and a value of ϵ' depending upon the inclination of the facet to the optic axis. On rotation, however, a position will be reached for which the light is travelling at right angles to a principal plane and here the maximum separation of shadow-edges, corresponding to the difference $\omega \sim \epsilon$ will be reached. Thus the true double refraction and the optic sign are determinable from any random section of a uniaxial crystal. A special case arises, however, if the table facet is cut at right angles to the optic axis (as it well may be in a crystal such as ruby of naturally tabular habit). Here all the family of central sections through ON are principal sections of the indicatrix, ellipses of semi-axes ω and ϵ. The true value of the double refraction is at once evident, as before, but neither shadow-edge moves during rotation of the stone, so that the optic sign is not directly determinable. If this is required, it may be possible to use some other facet. Alternatively, use may be made of the polarizing filter placed over the eyepiece of the refractometer, by means of which the direction of vibration corresponding to each shadow-edge may be determined. Since the optic axis is normal to the plane face of the refractometer, the ordinary ray must be propagated by vibrations parallel to this plane. If the filter is orientated to pass only light vibrating horizontally, the single shadow-edge seen will be that due to the ordinary ray. If this edge corresponds to the lower index the stone is optically positive, if to the higher index it is negative.

Similar considerations hold for biaxial crystals, and we may again note first some special cases. If the γ vibration-direction, OZ, is normal to the contact facet, the family of ellipses which determine the positions of the shadow-edges will all have a major semi-axis of this value and a minor semi-axis varying from β to α; one shadow-edge will remain stationary at the maximum reading, whilst the other moves downward to the minimum reading corresponding to α. If OX is the normal, α is the stationary value and the other edge moves from γ to β. If OY is the normal, the family of ellipses includes the two circular sections of the ellipsoid, and when light is travelling normal to these the shadow-edges coincide at the value for β. In the course of the rotation of the stone the moving shadow-edge twice crosses the fixed shadow-edge. If the normal ON lies in one of the circular sections but in a direction other than OY, both edges vary in position, but in moving as the stone is rotated they meet in the position on the scale corresponding to β.

Certain of these special cases occur in practice rather frequently, owing to the limitations imposed on the lapidary by the dominant habit of the natural crystals. Thus many orthorhombic and monoclinic substances will have the table facet parallel to a pinacoid; in orthorhombic substances this will necessarily be at right angles to one of the directions OX, OY, OZ of the indicatrix, as it will also in monoclinic substances in the case of the side pinacoid. Often, however, the selected facet will correspond to a random section of the indicatrix, and it is important here to justify the statement (p. 63) that the highest and lowest readings obtained from such a facet *always* correspond to the maximum double refraction possessed by the stone. Any random section of the indicatrix [1] will intersect the three principal planes at points P, Q, R (fig. 70). When, in the course of rotation of the stone, the light travels along OP it is travelling in the plane YOZ at right angles to OX and therefore one of the vibration-directions utilised will correspond to the value α of the refractive index. Similarly, when travelling along OQ, in the plane XOZ one vibration will be parallel to OY and the corresponding reading will be β, whilst travel along OR will give one shadow-edge corresponding to the value γ. During rotation of the stone, each of the two shadow-edges moves between two limiting values. The highest of these is, of course, easily identified as γ and the lowest as α. Of the two intermediate limiting values, one corresponds to β and the other to the particular value of refractive index for vibrations parallel to ON, the normal to the facet. To identify β, which is necessary if it is required to determine the optic sign, two courses are available. Observations may be made on a second, non-parallel, facet, to ascertain which of these intermediate limiting values is common to both and therefore corresponds to β. The mounting of the stone, however, may make this procedure impossible and use is then made of the polarizing filter over the eyepiece.[2] The values α, β, γ all correspond to vibrations parallel to the three orthogonal principal axes of the indicatrix, but vibrations parallel to the normal ON of a random section will lie in an intermediate direction. The stone is rotated to the position giving the α reading and the corresponding shadow-edge is

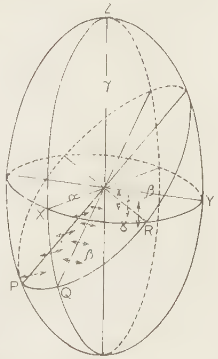

FIG. 70.—Diagram for directions of travel within the plane of a random section of a biaxial crystal.

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[1] L. J. Spencer, *The Gemmologist*, 1937, vol. VI, p. 235.

[2] E. J. Burbage and B. W. Anderson, *Mineralogical Magazine*, 1942, vol. XXVI, p. 251.

extinguished by adjusting the polarizer cap; it is then rotated to the position giving the lower intermediate limiting value, and the angle of rotation of the cap required to extinguish this edge is determined. The γ reading and the upper intermediate limiting value are treated similarly. If one of these angles is almost zero, whilst the other has an appreciable value, the latter is identified as corresponding to the arbitrary value for vibrations parallel to ON. In practice, however, one sometimes finds that the extinction positions are difficult to determine with sufficient sharpness for this distinction to be made.

We can now see, also, that for the determination of principal refractive indices by the method of minimum deviation (p. 73) it is necessary for the transmitted ray, in the final setting, to be travelling at right angles to a principal plane of the indicatrix. Since the ray at this setting travels symmetrically through the prism this implies that the faces used must be symmetrical over a principal plane. Whilst this requirement can often be met when using natural crystal faces it is extremely unlikely to be true of cut facets. Hence with a uniaxial stone the method of minimum deviation, whilst affording the true value of ω, will generally give an intermediate value ϵ' for the extraordinary index. With a biaxial stone the two values obtained are likely to lie anywhere between α and γ, the least and greatest of the principal refractive indices.

VII

COLOUR, DICHROISM AND ABSORPTION-SPECTRA

When white light passes through a cut stone, colour effects result which arise from more than one cause. The most conspicuous is the fundamental colour of the stone, which is due to its selective absorption of the light passing through it, and would characterize it, though possibly not so evidently, before it was cut. Intermingled with the colour in a transparent stone is the dispersive effect known as fire, which has already been discussed (p. 56). The property which certain species have of breaking up a ray of light falling upon a stone into two rays, which are differently absorbed, is responsible for the curious gleams that such a stone displays. This property, which is known as dichroism, is discussed in this chapter. In many instances the structure is discontinuous or wanting in homogeneity, so that such peculiar effects arise as opalescence, chatoyancy, asterism and silk; these were discussed in an earlier chapter.

A. COLOUR

All solid and liquid substances absorb light to some extent. If the action be slight and affect uniformly the whole of the visible spectrum, the stone appears to be colourless; if the action be greater but still uniform in its effect, the stone is still without colour and appears to be grey. Usually the various parts of the spectrum are differently absorbed; the stone then seems to be coloured. What is the apparent tint depends not merely upon the parts of the spectrum that are transmitted but also upon their relative intensities. The eye, unlike the ear, has not the power of analysis and cannot of itself determine how a composite colour has been made. Indeed, so far as the eye is concerned any tint may be exactly matched by compounding in the requisite proportions three simple primary colours: red, green and violet.

Owing to the inability of the eye to analyse a colour, stones may appear to possess very similar tints, although the light producing them may have come from different parts of the spectrum. This fact may be betrayed, if the stones be viewed through a suitable filter, by the difference in its effect. A potent weapon of this kind is the Chelsea filter (devised by B. W. Anderson and C. J. Payne) which transmits a band in the deep red and another in the yellowish-green of the spectrum. It is most useful for distinguishing emerald from its imitations. Most genuine stones will appear red or pinkish according to the depth of the intrinsic colour, whereas imitations remain greenish in appearance. Of natural green gemstones demantoid and certain green zircons will appear reddish through the filter, though not so pronounced a tint as emerald, but in their natural colour they differ markedly from emerald; on the other hand, green corundum, green tourmaline, peridot and imitations made of green glass all appear greenish through the filter.

The filter has further uses. Synthetic blue spinel appears red through it, but the gemstones that it resembles in colour—sapphire, blue zircon and aquamarine—are greenish or greyish; cobalt paste-imitations of sapphire appear reddish through the filter. Ruby, both natural and synthetic, shows through it a characteristic brilliant fluorescent red.

As has been shown, the apparent colour of a stone depends upon the parts of the solar spectrum which it absorbs. An instructive example is provided by alexandrite, a variety of chrysoberyl. The middle part of the spectrum—the yellowish green—is removed, and the transmitted light is balanced between the red and the violet ends of the spectrum. In daylight the stones appear green, but in artificial light, which is relatively stronger in the red, the balance swings the other way and they turn a pronounced raspberry-red (plate XVII). The curious phenomenon is complicated by the strong dichroism that is characteristic of this variety of chrysoberyl.

In permanence of colour the inorganic excels the organic world. Every careful housewife knows only too well the necessity of tempering the blaze of the sun if her carpets and other fabrics are not perceptibly to fade within a very brief span of time. Even so, whatever may have been the expenditure of care, the most brilliant of colours have tended towards a uniform grey, as ancient tapestries show. The colours of gemstones, on the other hand, are far more durable, and so far as can be judged from comparison with freshly mined material the tints of ancient jewellery have hardly altered in the course of ages. There are, however, exceptions. Pink, for instance, is a relatively fugitive tint, and red tourmaline in the course of a century or so of exposure to daylight will turn distinctly yellowish. Certain shades of brown, as for instance in the topazes from Siberia, fade away completely on exposure to strong daylight.

The colour of many gemstones may be altered or even driven off altogether by the application of heat. Since no material is added to the stones, the cause must clearly be ascribed to some permanent rearrangement of the atoms of the tinctorial agent. The most familiar example of this phenomenon is the beautiful pink topaz which has long been a favourite jewel. Topazes of a reddish tint are very rare in nature, but it was discovered that the yellow stones from Brazil, if carefully heated and cooled, assumed a permanent pink colour. Some zircons, if similarly treated, will completely lose their colour, and in view of the large colour-dispersion or fire of zircon such stones, when cut as brilliants, may masquerade as diamonds with fair success; their refraction, however, is not high enough to prevent an appreciable proportion of the light falling upon them from escaping through the back, with consequent loss of brilliance. Under different heating conditions, on the other hand, zircon will yield those lovely blue stones which are such an attractive feature of the jewellery of to-day. Less familiar changes of colour through heating are: in quartz from violet (amethyst) to orange, yellow and green, and from smoky colour to yellow; beryl from pale-green to blue; and corundum from violet and yellow to rose-pink and colourless respectively. Generally it may be said that the effect of heating is to weaken the colour.

The colour of some gems is also affected by irradiation, when exposed to a radioactive substance or treated in a nuclear reactor. Diamond is coloured green (p. 261), which may be changed to brown by heating. A pale brown tint is imparted to colourless corundum and quartz; rose-quartz will assume a somewhat similar shade of colour. X-rays have a transitory effect.

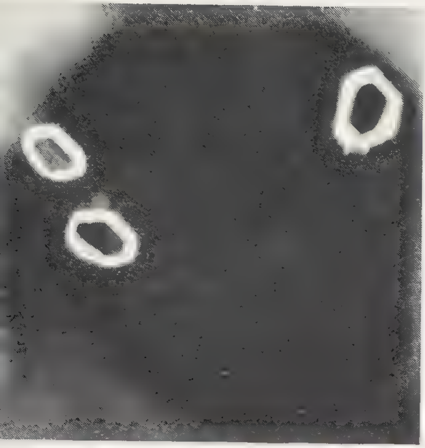
Great scope obviously is possible when dealing with porous material like agate and chalcedony, since any kind of foreign matter may be absorbed into the empty interstices; its arrangement, on the other hand, is necessarily restricted by the shape of the interstices. The agate, which is extensively used for umbrella handles and other worked articles, is almost invariably dyed, because the grey and pale shades of the natural material fail to appeal to sophisticated eyes. The art of staining agate and chalcedony is no new discovery, and the possibility was to some extent known to the Romans. By soaking a suitable piece in honey and afterwards heating it they succeeded in obtaining bands, deep black in colour. A similar result is achieved nowadays by means of the action of sulphuric acid upon a sugar solution impregnating the interstices. By either method the final product is something akin to lamp-black, having a dense black tint. By merely heating a piece that has been soaked in a sugar solution, a brown colour is obtained. Since the interstices often contain iron hydroxide, the action of warm hydrochloric acid produces a citron-yellow tint of varying depth; a similar treatment with nitric acid results in a red colour. Apple and grass shades of green may be obtained by the use of solutions of nickel and chromium salts respectively. Various shades of blue are brought about by impregnating the interstices with potassium ferrocyanide and acting upon it with a solution of ferric sulphate, the product being Berlin blue, ferric ferrocyanide. Chalcedony stained in a similar manner is passed as 'Swiss', 'German' or 'false' lapis-lazuli. Although aniline dyes provide a large variety of different shades of colour, their use for this purpose is not recommended, because of their tendency to rapid fading in sunlight.

The colour of gemstones is often due to the admixture of some metallic oxide, which has no essential part in the chemical composition and is present in such minute quantities as to be almost imperceptible by even the most delicate chemical analysis. The spectroscope is, however, more searching, and the presence of certain of the elements may be betrayed by the bands that they impose upon the spectrum of the light transmitted by the stone. The most effective tinctorial agents are the following: iron, which in the ferric state is responsible for yellow shades, in the ferrous state for the familiar bottle-green hue, and in the form of a ferric compound for the violet colour of amethyst; chromium, which produces red tints, as in ruby, and green ones, as in emerald; copper, which, when accompanied by hydroxyl, is responsible for the colour of turquoise (greenish tints in torquoise being due to the presence of iron), dioptase, azurite and malachite; titanium, which gives a blue colour; lithium, which yields a rather impermanent pink tint; and manganese, which produces a beautiful rose-red or pink colour, as in rhodonite and rhodochrosite. Other elements which play an important part in the coloration of gemstones are vanadium, cobalt, nickel, and perhaps gallium and caesium. Gemstones may be said to be idiochromatic,[1] if the colouring agent be an essential constituent of the chemical composition, and allochromatic,[2] if it be extraneous to it. The absorption-spectra are discussed later in this chapter.

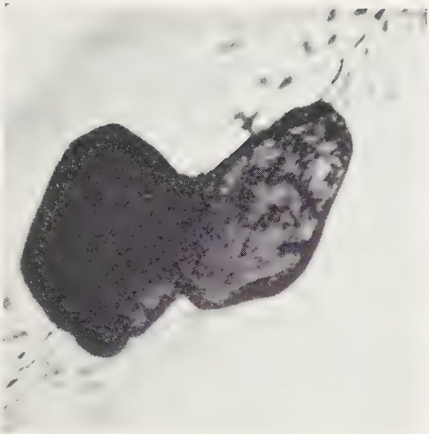
The colour is by far the least reliable character that may be employed

[1] From the Greek words ἴδιος (own) and χρῶμα (colour).

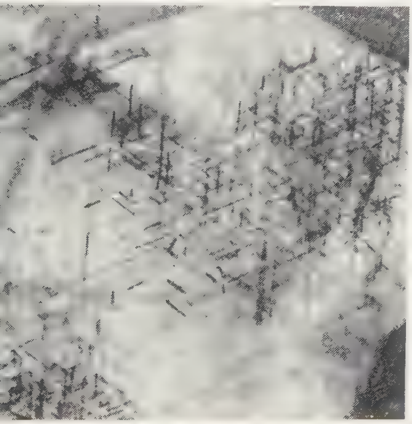
[2] From the Greek words ἄλλος (other, different) and χρῶμα (colour). Allochromatic is also used in two other meanings: of or pertaining to change of colour; exhibiting or seeing colours different from what they really are.



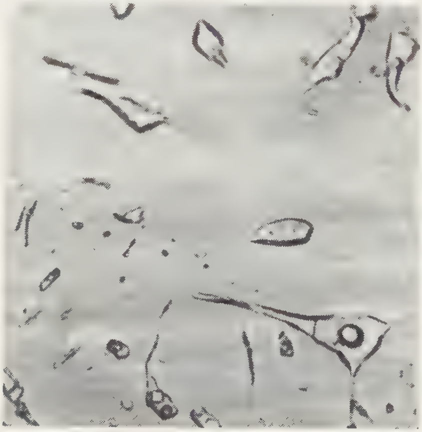
1. Group of euhedral quartz crystals in diamond from Brazil. × 75



2. Rounded grains of garnet in sapphire from Ceylon. × 125



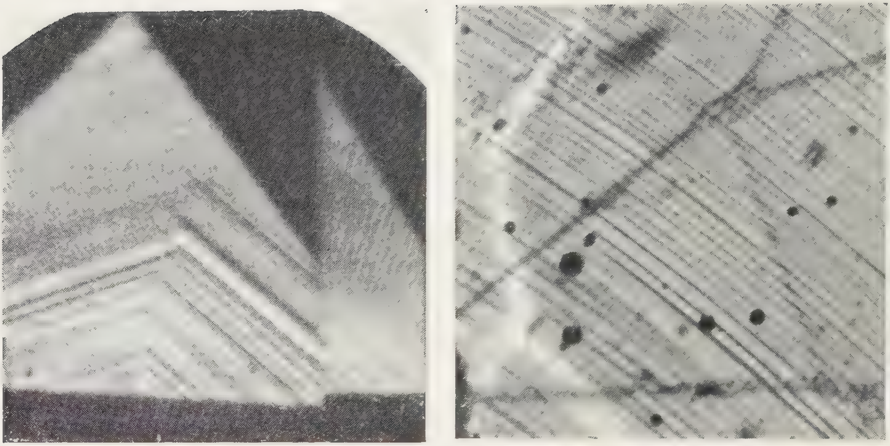
. Oriented rutile crystals in ruby from Burma. × 250



4. Three-phase inclusions in emerald. × 200

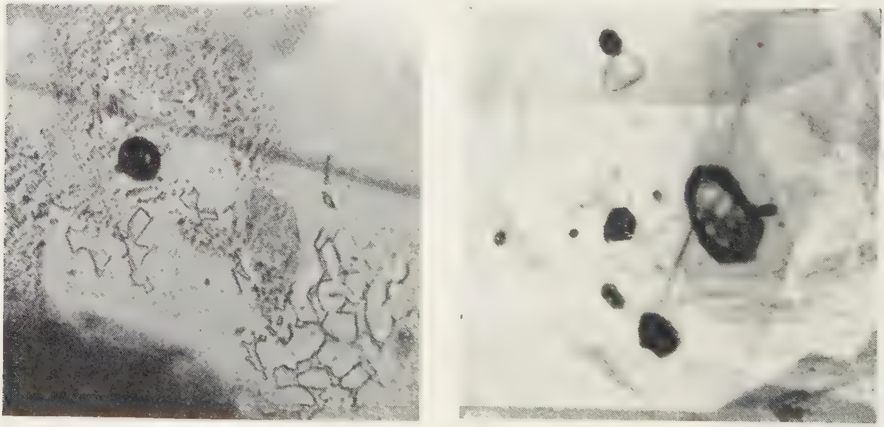
IV. GEMSTONE INCLUSIONS

(*Photos by E. Gübelin. Reprinted from the* Journal of Gemmology



1. Angular intersection of zonal striations in sapphire from Burma. × 40

2. Curved striae and gas bubbles in synthetic corundum. × 75



3. Diagnostic inclusion picture of ruby from Siam. × 150

4. Diagnostic inclusion picture of ruby from Burma. × 150

V. GEMSTONE INCLUSIONS

(*Photos by E. Gübelin. Reprinted from the* Journal of Gemmology) for the identification of a stone, because species may show very different tints and different species may supply stones not very dissimilar in colour. Thus quartz in spite of the simplicity of its composition displays extreme differences of tint, while on the other hand a ruby and an almandine may appear not unlike to a casual glance. Nevertheless, certain varieties do possess a distinctive colour, emerald being the most striking example, and in other instances the trained eye can appreciate certain characteristic subtleties of shade. The colour is at least the most obvious of the physical characters, and serves to provide a rough division of the species; accordingly in the table in Part IV the gemstones are arranged by the tints that they usually display.

B. DICHROISM

The two rays into which a doubly-refractive stone splits up the incident ray of light falling upon it are often differently absorbed by it, and consequently on emergence they appear of different colours; such stones are said to be dichroic. The most striking instance among gemstones is a deep-brown tourmaline, which is quite opaque to the ordinary ray except in very thin sections. The light transmitted by a plate cut parallel to the crystallographic axis is therefore plane-polarized (p. 82); before Nicol's invention of the prism known by his name this was the ordinary method of obtaining plane-polarized light, and similarly the complete absorption of one of the rays produces the polarizing property of the artificial substance called polaroid (p. 119). In kunzite and cordierite, too, the difference in colour of the two rays is so pronounced that it is obvious to the unaided eye; kunzite with its lovely shade of lilac is a beautiful example of dichroism.

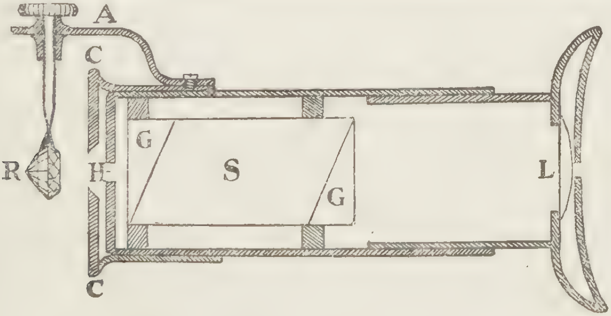


FIG. 71.—Dichroscope (*actual size*).

Where the contrast between the twin colours is not obvious we require the use of an instrument called the dichroscope, which enables them to be seen side by side and thus directly compared. Fig. 71 illustrates in section the construction of an instrument of the kind. It consists essentially of a rhomb of Iceland-spar, *S*, of such length as to give two contiguous images (fig. 72) of a square hole, *H*, in the one end of the tube containing it. In some instruments the terminal faces of the rhomb have been ground at right angles to its length, but the more usual practice at the present time is to cement prisms of glass, *G*, on to the two ends, as shown in the figure. A cap, *C*, with a slightly larger hole, which is circular in shape, fits on to the end of the tube, and can be moved along it or revolved round it, as may be desired. The stone, *R*, to be tested may be directly attached to it by means of some kind of wax or cement in such a way that light which has traversed it passes through the hole, *H*, of the instrument; the cap at the same time permits of the rotation of the stone about the axis of the main tube of the instrument. The dichroscope shown in the figure has a still more convenient arrangement; it is provided with an attachment, *A*, by means of which the stone can be turned about an axis at right angles to the length of the tube and thus examined in different directions. At the other end of the main tube is placed a lens, *L*, of low power, for viewing the twin images; the short tube containing it can be pushed in and out for focusing purposes. Many makers now place the rhomb close to the lens, *L*, and are so enabled to use a much smaller piece of Iceland-spar; material suitable for optical purposes has long been scarce.

FIG. 72.—Field of the dichroscope.

Suppose that a plate of tourmaline, cut parallel to its crystallographic axis, be fastened to the cap of the dichroscope and the latter be rotated. We should notice, on looking through the instrument, that in the course of a complete revolution there are two positions, orientated at right angles to one another, in which the tints of the two images are identical, the positions of greatest contrast of tint being midway between. If we examine a uniaxial stone in a direction at right angles to its optic axis, we obtain the colours corresponding to the ordinary and the extraordinary rays. In any direction less inclined to the axis we still have the colour corresponding to the ordinary ray, but the other colour is intermediate in tint between it and that corresponding to the extraordinary ray.

The phenomenon presented by a biaxial stone is much more complex. It possesses three principal colours, which are visible in differing pairs in the three principal optical directions; in other directions the tints seen are intermediate between the principal colours. In stones of low crystallographic symmetry the phenomenon is further complicated by the change in the principal directions with the wave-length of the corresponding ray. Since biaxial stones have three principal colours, they are often said to be trichroic or pleochroic; but in any one direction they cannot show more than two colours or in other words they must be dichroic. No difference in colour will be shown in directions in which the stone is singly refractive or nearly so, and it is therefore always advisable to examine a stone in more than one direction, lest the first happen to be one or close to one of single refraction.

For determinative purposes it is not necessary to note the exact shades of tint of the twin colours, because they vary with the inherent colour of the stone, and are therefore not constant even for the same species; the important point is to notice whether there be any variation of colour, and, if so, what its strength may be. Dichroism is a result of double refraction, and cannot exist in a singly-refractive stone. The converse, however, is not true; it by no means follows, because no dichroism can be detected in a stone, that it is singly refractive. A colourless stone, for instance, cannot possibly be dichroic, and many coloured, doubly-refractive gemstones—for example, some zircons—exhibit either no dichroism or so little that it is imperceptible. The character is always the better displayed the deeper the inherent colour of the stone. The deep-green alexandrite, for instance, is far more dichroic than the lighter coloured varieties of chrysoberyl.

If the stone under examination be attached to the cap of the dichroscope or otherwise placed before the hole, *H*, the table facet should be turned towards the instrument in order to assure that the light passing into it has actually traversed the stone. If little light enters through the opposite coign, a drop of oil placed thereon will overcome the difficulty (p. 61). It is important, for reasons stated above, to examine the stone also in directions as far as possible across the girdle. A convenient, though not strictly accurate, method is to lay the stone with the table facet on a table, and examine the light which has entered the stone and been reflected at that facet. The stone may be rotated on the table, and observations may thus easily be made in different directions in the stone. Care must be exercised in the case of a faceted stone not to mistake the alteration in tint due to colour-dispersion for a dichroic effect.

Dichroism is an effective test for ruby, since its twin colours—purplish and yellowish-red—are in marked contrast, and readily discriminate it from other red stones. Again, one of the twin colours of sapphire is considerably more yellowish than the other, and serves to distinguish it from other blue stones; blue spinel, for instance, is singly refractive and, of course, shows no difference of tint when examined with the dichroscope, and blue zircon displays dichroism from deep blue to nearly colourless.

As an alternative to the dichroscope a polaroid plate (p. 119) may be used, although it is obviously far less convenient, since only one ray is transmitted by it. It is therefore necessary to observe whether the tint varies as the plate is rotated parallel to its own plane and to what extent. Since the two transmitted rays cannot be simultaneously compared, weak dichroism may escape notice. The difficulty may, however, be overcome to a considerable extent by the use of two small plates, which are optically at right angles to one another, care being taken to ensure that they are illuminated by the same beam.

C. ABSORPTION-SPECTRA

The study of the chromatic character of the light transmitted by a coloured stone is of no little value and interest. As was stated above, the eye has not the power of analysing light, and, to resolve the transmitted rays into their component parts, an instrument known as a spectroscope is needed. The small, direct-vision type has ample dispersion for this purpose. An instrument using a diffraction grating is to be preferred to the prism form, because in the former the intervals in the resulting spectrum corresponding to equal differences of wave-length are the same, whereas in the latter they diminish as the wave-length increases, and accordingly the red end of the spectrum is relatively cramped.

For the resulting absorption-spectrum to be satisfactorily clear ample illumination of the stone under examination is demanded. A convenient plan is to place the stone, table facet downwards, on the stage of a low-powered microscope, and concentrate the light from the source upon it by means of the condenser underneath. The eyepiece is removed and a direct-vision spectroscope is attached or may readily be held, so that its slit is in the focal plane, the microscope being focused until the optical field is flooded with light. If the stone be too highly refractive to allow sufficient light to emerge through the base, it should be placed in oil; if a suitable bath should not be available a few drops on the base may serve the purpose.

If white light be studied with a spectroscope, the slit will be seen to be spread out into a spectrum or a ribbon of light, which is violet at the one end and passes through shades of green and yellow to red at the other end. The spectrum, however, does not really end in either direction, as it appears to do; it merely means that our eyes are sensitive only within these limits. The ribbon of light is similar in general appearance to a cross-section of a rainbow, which, indeed, is produced by similar refraction. Lying beyond either end of the visible spectrum many octaves of radiations have been recognized. Passing beyond the violet end we have the rays which most strongly affect the ordinary photographic plate, then the X-rays and cosmic rays. Beyond the red end we find the heat rays, which we can feel with the skin though we cannot see them, and with ever-increasing wave-length we come to the electromagnetic waves used in broadcasting. It may perhaps be wise to sound a cautionary note. The rays of short wave-length lying beyond the violet end of the visible spectrum unlike those of long wave-length lying beyond the red end are not immediately detectable by the senses, as many who have injudiciously exposed themselves to strong sunlight have learned by painful experience. Far more serious are the results of exposure to rays of still shorter wave-length, and prospective users of X-ray apparatus will be well advised to obtain preliminary instruction in its use, even though the manufacturers will have introduced proper precautions to guard against mishap.

RADIATION RANGES (in millimetres)

Broadcasting	2,000,000 — 3
Infra-red	3 — 0·00078
Visible	7800×10^{-7} — 3800×10^{-7}
Ultra-violet	3800×10^{-7} — 10×10^{-7}
X-rays	10×10^{-7} — 1×10^{-7}
Gamma rays	100×10^{-9} — 1×10^{-9}
Cosmic rays	100×10^{-11} — 1×10^{-11}

The wave-lengths of light rays, being very short, cannot be expressed conveniently by normal units, and a much smaller one, called the Ångström after the Swedish physicist A. J. Ångström (1814–74), is used; it is equal to 10^{-7} mm., that is, ten million of these units equal one millimetre. The symbol used for the unit is the initial letter, but it is now often printed as a simple capital A.

Although the visible spectrum may be described as passing from violet at the one end through green and yellow to red at the other end, the transition from one shade to another is so subtle that where the transition takes place is largely a matter of opinion; the figures in the table below must therefore be regarded as approximate only. The spectrum of sunlight shows absorption-lines due to the passage of the rays through vapour, mainly in the sun's atmosphere but also in the air. The most conspicuous of them bear the letters originally assigned to them by the physicist J. Fraunhofer (1787–1826). The corresponding wave-lengths have been accurately determined.

APPROXIMATE RANGE OF PRINCIPAL COLOURS IN VISIBLE SPECTRUM, AND WAVE-LENGTHS OF PRINCIPAL FRAUNHOFER LINES, EXPRESSED IN ÅNGSTRÖM UNITS.

Red	7800–6400	*A*	(O)	7606
		B	(O)	6870
Orange	6400–5950	*C*	(H)	6563
		D_1	(Na)	5896
Yellow	5950–5700	D_2	(Na)	5890
		E	(Fe)	5270
Green	5700–4900	b_1	(Mg)	5184
		b_2	(Mg)	5173
Blue	4900–4500	b_4	(Mg)	5168
		F	(H)	4861
Indigo	4500–4250	*G′*	(H)	4241
		G	(Ca, Fe)	4308
		g	(Ca)	4227
Violet	4250–3800	h	(H)	4102
		H	(Ca)	3969
		K	(Ca)	3934

It may be noted that the lines of the sodium doublet lie so close together that they can hardly be separated by an ordinary small spectroscope and for normal purposes their separation may be disregarded; similarly, the corresponding bright lines in the sodium spectrum may be regarded as composing a single line. Another point is that the lines *B* in the red and *G* in the violet are near the limits of easy vision of the spectrum, and for that reason they have been selected as the standard interval on which to base the colour-dispersion of gemstones. As was remarked in a previous chapter, the figures corresponding to the interval between the *C* and *F* lines have been included, because this interval is the standard adopted for the optical glasses.

The absorptive properties of all coloured doubly-refractive substances vary more or less with the direction in which light traverses them, the extent depending upon the amount of dichroism that they possess, but the variation is not ordinarily noticeable unless the dichroism be unusually strong. If now the light that has passed through a coloured stone be examined with a spectroscope, we shall observe that the spectrum is crossed vertically by dark bands, which may be either wide with diffuse and blurred edges or narrow with sharp edges. Stones characterized by the latter type of spectra are said to display absorption-bands. Church[1] in 1866 was the first to call attention to such bands, in the case of zircon. Sorby,[2] who likewise studied the zircon bands, thought at first that they

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[1] Sir Arthur Herbert Church, F.R.S. (1834–1915), 'Micro-spectroscope investigations,' *Intellectual Observer*, 1866, vol. 9, p. 291.

[2] Henry Clifton Sorby, F.R.S. (1826–1908), 'On jargonium, a new elementary substance associated with zirconium,' *Proc. Roy. Soc.*, 1869, vol. 17, pp. 511–15.

portended the existence of a new element, to which he gave the name jargonium, but subsequently discovered that they were caused by the presence of a minute trace of uranium. During recent years absorption-spectra of gemstones have attracted increased attention, and have been found to possess considerable determinative value in the case of the following gemstones.[1]

Zircon is discussed first, because its absorption-spectrum was the earliest of any shown by the gemstones to be described, as was noted above, and because it is still the most remarkable of the kind. Next are considered those absorption-spectra which can be ascribed to the presence of chromium, then those in which iron is the principal agent, and finally those of which the cause is still unknown or uncertain. As an addendum the absorption-spectra of synthetic and imitation stones are described.

i Absorption-spectrum of Zircon

The principal bands in the absorption-spectrum of zircon are as follows: 6910 (s.); 6830 (m.); 6625 (m.); 6535 (v.s.); 6210 (m.w.); 6150 (m.w.); 5895 (s.); 5625 (s.); 5375 (s.); 5160 (m.); 4840 (s.); 4325 (s.).[2]

The absorption-spectrum of zircon (plates I, XXII) when fully developed, is more spectacular than that shown by any other gemstone. Indeed, in the greenish-brown stones from Burma no fewer than thirty-six bands in the visible spectrum have been observed. The strongest of them are also displayed by many of the zircons from Ceylon, which show at the maximum fourteen bands, of which the twelve most prominent ones are those stated in the list above. The band at 6535 is the strongest and the most persistent, and is consequently of the greatest value for discriminative purposes in the case of the blue and white stones that are so popular to-day, since they invariably exhibit it as a narrow line in the red part of the spectrum, though occasionally so faintly that it may escape the inexperienced eye. Whether completely or partially developed, the absorption-spectrum of zircon is so distinctive that a stone may by its means be identified with certainty; its value as a test will be appreciated when it is realized that the refractive indices are beyond the range of the ordinary refractometer. On the other hand,

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[1] The information on the absorption-spectra has been supplied by B. W. Anderson and C. J. Payne. See also a long series of articles by these authors, *The Gemmologist*, 1953, vol. XXII onwards.

[2] The wave-lengths throughout are expressed in Angström units (10^{-7} mm.) The letters in the brackets have the following meanings: *v.s.* very strong; *s.* strong; *m.* moderate or moderately; *w.* weak.

it must be remembered that the absence of the characteristic absorption-spectrum is not conclusive, since some zircons, especially the red ones, may show no bands at all.

ii Absorption-spectra Due to Chromium

The absorption-spectra which are the result of the presence of chromium are extremely characteristic, and are displayed by a number of gemstones. They may be divided into two groups, namely, those shown by red and by green minerals respectively. Both have in common two narrow lines, forming a doublet, in the deep-red part of the spectrum, a broad absorption-band in the orange, or in the yellow and green, and a strong absorption of the violet. Other narrow bands may be visible in the red in addition to the doublet, and in some instances in the blue as well.

a Red Group

1 *Ruby*

In the absorption-spectrum of ruby the principal bands are at: 6942, 6928 (doublet, v.s.); 6590 (m.); 5950–5200 (v.s.); 4765 (v.s.); 4750 (s.); 4685 (v.s.).

Ruby has a particularly characteristic absorption-spectrum. The doublet in the deep red is reversible, and appears as bright lines against a dark background, when viewed in scattered light. This phenomenon arises from the strong fluorescence of ruby, which is excited by violet and ultra-violet rays and consists preponderantly of the two lines of this doublet. It is only in direct transmitted light that these lines are dark, that is, are absorption-lines. This fluorescence doublet is such a sensitive test for the presence of chromium in corundum that it can be detected in varieties of other colours, such as purple or mauve sapphires, and even those blue sapphires which acquire a purple tinge in artificial light. In addition, the three lines in the blue are characteristic and of value for the identification of ruby, since neither spinel nor pyrope show any lines in this part of the spectrum.

2 *Red Spinel*

In the absorption-spectrum of the red spinel the principal bands are at: 6855, 6840 (doublet, m.w.); 6560 (w.); 5950–4900 (v.s.).

The above absorption-spectrum is characteristic of the pure red spinel only; it is not nearly so intense in the pink spinel, but in this instance fluorescence lines may appear, though they are neither so intense nor so sensitive as in the case of ruby, and, moreover, do not correspond exactly to any of the bands. It should be noted that, whereas in ruby the doublet appears in a small spectroscope as a single sharp line in the red end of the spectrum, in spinel there is a group of five lines, of which the two strongest at 6870 and 6750 form a distinctly separated pair; this fluorescence is visible in pink spinel only. The absorption-spectrum includes, besides the moderately weak doublet, several fine lines in the red and orange, of which the strongest is included in the list above; the absorption of the yellow and green is very intense.

It must be noted that many of the reddish spinels owe their colour chiefly to elements other than chromium, and such stones do not exhibit the absorption-spectrum which has just been described.

The blue spinel is considered below.

3 *Pyrope*

In the absorption-spectrum of pyrope the principal bands are at: 6870 (w.); 6850 (doublet, w.); 6200–5200 (v.s.).

The doublet in the red is perhaps too weak to be relied upon for the identification of pyrope. The broad band in the yellow and green, on the other hand, is very intense, and is distinguished from a similar band in the absorption-spectrum of spinel by its position nearer the red.

Pyrope from Bohemia is not so transparent in the blue part of the spectrum as that from Arizona or Kimberley, and on that account is inferior in tint to the other two kinds. It should be noted that besides the bands due to chromium the principal almandine band at 5050 is visible in the absorption-spectrum displayed by all pyrope from Bohemia and frequently by pyrope from the other two localities as well.

It must be emphasized that the absorption-spectrum just described is displayed only by pyrope which owes its colour mainly to chromium, and that the pale reddish-violet garnets belonging to the pyrope-almandine series, such as rhodolite and the variety from Ceylon that is misnamed 'Kandy-spinel', show a weak almandine and not a chromium absorption-spectrum.

4 *Pink Topaz*

In the absorption spectrum of pink topaz a faint line can sometimes be detected in the red end of the spectrum at 6820. This is probably an unresolved doublet, by analogy with the strong doublets seen in ruby, emerald, etc. In common with most chromium spectra this line is "reversible"—i.e. it can be seen as a bright fluorescence line when the stone is strongly illuminated and viewed obliquely.

Apart from its shorter wave-length, the relative faintness of the line should prevent confusion with the brilliant fluorescence doublet seen in pink sapphire.

b Green Group

1 *Emerald*

In the case of emerald the absorption-spectra corresponding to the ordinary and extraordinary refractive indices differ, the principal bands being at:

Ordinary: 6820, 6795 (doublet, m.s.); 6370 (m.); 6300–5800 (m.).
Extraordinary: 6820 (s.); 6795 (m.s.); 6620 (m.); 6460 (m.).

This is a typical green chromium absorption-spectrum. As is indicated above, there are really two absorption-spectra for emerald, since the ordinary (yellow-green) and the extraordinary (blue-green) rays show distinct differences. The two lines in the doublet in the red can be seen distinctly separated even with a small spectroscope; they are shown by both rays, but their relative intensity is slightly different for the extraordinary ray. The broad absorption band, which is in the orange-yellow, is not nearly so intense as in the red chromium absorption-spectrum; in the case of the extraordinary it is so faint as to be negligible. In some instances faint lines are visible in the blue.

This absorption-spectrum is extremely characteristic, and provides a test for emerald, it being remembered that synthetic emerald has the same absorption-spectrum and the fine, translucent, green jadeite (*v.* below) one very similar.

2 *Alexandrite*

In the case of alexandrite, which is pronouncedly dichroic, the absorption-spectra corresponding to the principal optical directions, that is the axes of the indicatrix (p. 88), are distinctly different. We shall describe the two that correspond to the green (slow, or greatest refractive index) and purple (fast, or least refractive index) rays respectively. The principal bands in the two absorption-spectra are at:

Green ray: 6795 (v.s.); 6774 (m.); 6650 (w.); 6550 (m.w.); 6490, 6450 (m.w.); 6400–5550 (m.s.).
Purple ray: 6795 (w.); 6774 (s.); 6550 (m.w.); 6450 (m.w.); 6050–5400 (m.s.).

The alexandrite absorption-spectrum may be considered to be a connecting link between the red and the green types of chromium absorption-spectra. The green ray shows on the whole an absorption-spectrum similar to that of the purple ray but richer. The most marked difference between them lies in the broad absorption band in the red, which is less extensive and is displaced towards the green, and accounts for the striking contrast in colour between the two rays.

The absorption-spectrum corresponding to the orange (mean refractive index) ray is inconspicuous in character, and the doublet in the red is only faint.

Like emerald and ruby, alexandrite shows in its absorption-spectrum lines in the blue, but they are weak; they are most distinct in the absorption-spectrum given by the purple ray.

3 *Jadeite*

In the absorption-spectrum of jadeite the principal bands are at: 6915 (s.); 6550 (m.); 6300 (w.); 4370 (s.); 4330 (w.).

The band with centre at 6915 is almost certainly a doublet, of which the components are at 6940 and 6890, but owing to their hazy definition they cannot be clearly resolved. The other two bands likewise are ill-defined. This absorption-spectrum is confined to the much-prized green jade. In addition to the bands mentioned there is a strong, narrow band at 4370 in the violet, which is shown by translucent jadeite of every colour, but most strongly by the pale-mauve variety. A fainter band may also be detected at 4330. These bands are almost certainly due to ferric iron, and are very similar to those seen in the yellow varieties of the closely-related mineral spodumene.

It may be remarked that the absorption-spectrum of nephrite, the other mineral properly classed under jade, includes an obscure band at 6890 and a band at 6630, thus indicating the presence of chromium.

Several other gemstones, such as chrome-diopside, demantoid, blue kyanite, and some enstatite may also show traces of the chromium bands.

iii Absorption-spectra Due to Iron

a Ferric Group

1 *Sapphire* (*green and blue*)

In the absorption-spectrum of the green and blue sapphire the principal bands are at: 4710 (m.); 4600 (m.s.); 4500 (v.s.).

The above absorption-spectrum belongs essentially to the green corundum, in which the 4600 and 4500 bands appear as a single band of great intensity, extending from 4630 to 4470. Of the three bands the one at 4500 is the most persistent, and may almost always, even if only faintly, be shown by blue sapphires; this band has never been seen in connexion with a synthetic stone, and, if it be present in the absorption-spectrum of a stone, its natural origin may be considered certain. In the case of blue sapphires of really fine colour the yellow part of the spectrum may be perceptibly absorbed.

2 *Andradite (Demantoid)*

In the absorption-spectrum of andradite the principal band is at 4430 (v.s.).

Andradite shows in its absorption-spectrum a very intense band with its centre at 4430, which is due to ferric oxide and may therefore be said to be idiochromatic, since iron is an essential constituent of andradite garnet, whereas all the bands hitherto considered have been allochromatic.

The demantoid variety of andradite owes its beautiful green colour chiefly to chromium. Consequently, in its absorption-spectrum there is a strong absorption of the violet, as was described above. This has the effect in the case of stones of moderate quality of sharply cutting off the blue end of the spectrum at about 4470. In demantoid that is exceptionally rich in chromium even this effect may be masked; but in the case of such stones two vague bands due to chromium, in the orange at 6400 and 6220, may be observed.

3 *Chrysoberyl*

In the absorption-spectrum of chrysoberyl (other than alexandrite) the principal band is at 4440 (s.).

This band is most intense in the brown chrysoberyl from Ceylon, is in this instance about 250 units in breadth, and may be accompanied by weak, vague bands at 5040 and 4860. In the case of yellow chrysoberyl only the 4440 band is visible, in moderate strength, and is narrower, being only about 100 units in breadth.

The absorption-spectrum of alexandrite has already been described.

4 *Epidote*

In the absorption-spectrum of epidote two principal bands, 4750 (s.) and 4550 (s.), are visible, if the general absorption of the blue is not too intense.

b Ferrous Group

1 *Almandine*

In the absorption-spectrum of almandine the principal bands are at: 5760 (s.); 5270 (s.); 5050 (v.s.); 4620 (m.).

The absorption-spectrum of almandine (plate I) was mentioned by Church in 1866 in the same communication, in which he described the bands shown by zircon. The three bands in the green are very strong and broad, and two of them with centres at 5270 and 5050 can hardly be separated in true almandine. Many pyropes, too, show these three persistent bands, and not infrequently they are to be seen in the case of hessonites from Ceylon. Besides these bands, there are four more in the visible spectrum; a broad, weak band at 6170 in the orange, a narrow, weak band at 4760 in the blue, another at 4380, and a broader one at 4270, both in the indigo. Two additional bands lie just beyond the limit of vision.

2 *Olivine (Peridot)*

In the absorption-spectrum of peridot the principal bands are at: 4910 (m.s.); 4730 (m.s.); 4530 (m.s.).

This absorption-spectrum is characteristic of peridot, and provides a useful discriminative test. The bands appear in any orientation of the stone, but are decidedly at their strongest in directions corresponding to the mean refractive index.

3 *Sinhalite*

The absorption spectrum of the recently-discovered gem mineral sinhalite is very similar to that of olivine, and this fact was contributory to the confusion of the two species. Sinhalite has bands at: 5260 (w.); 4930 (m.s.); 4750 (m.s.); 4630 (m.s.); 4520 (m.); 4350 (s.) as a cut-off.

The most striking difference from the olivine spectrum is the appearance of the band at 4630, which is absent in olivine.

4 *Blue Spinel*

In the absorption-spectrum of blue spinel the principal bands are at: 4800 (m.s.); 4590 (s.).

When fully developed, the absorption-spectrum of blue spinel contains no fewer than ten bands, most of which are, however, rather vague. The one at 4590 is very persistent and is visible in the case of spinels containing less than 2 per cent of iron oxide.

5 *Enstatite and Diopside*

The absorption spectrum of enstatite is very striking owing to the appearance of a strong, narrow absorption band in the blue-green at

5060. This is particularly marked in the brown enstatite from Burma, which shows in addition a broader, moderately strong band at 5480 as well as fainter bands in the blue.

Certain diopsides, especially the attractive chrome-diopside from Burma, show a spectrum very similar to that of enstatite, but in place of the single strong line in the blue-green there are two, of almost equal intensity, at 5080 and 5050. Both green enstatite and chrome diopside owe their colour in part to chromium, and show rather ill-defined narrow bands in the red, due to this element.

iv Absorption Spectra Due to Manganese

Minerals owing their colour to manganese tend to be pink or orange in colour. Their absorption spectra are rather typical, consisting of bands in the blue and violet increasing in strength towards the shorter wavelengths. Photography has revealed further bands in the near ultra-violet in certain cases.

1 *Spessartite*

The rare and attractive manganese garnet, spessartite, often shows in some degree the absorption bands of almandine, as the iron-garnet molecule is usually present. The distinctive spessartite bands consist of two rather weak bands in the blue at 4950 and 4845, followed by a stronger one at 4620. A powerful band at 4320 is often the last that is visible, but in some cases further strong and fairly narrow bands can be seen at 4240 and 4120. The last-named band is particularly intense.

2 *Rhodonite and Rhodochrosite*

The pink manganese silicate rhodonite and the carbonate rhodochrosite of very similar appearance, which are used as ornamental minerals, also show absorption bands typical of manganese. Unfortunately, in the translucent specimens usually met with, only a broad band in the green centred near 5500 can be seen in each case. Even in the rare cases where the minerals are found in the transparent state, and further bands in the blue and violet can be seen, these are so similar that they do not afford a safe means of distinguishing between the two species.

iv Absorption-spectra of Uncertain Origin

1 *Diamond*

In diamonds of the Cape series, grading from off-white to a deep yellowish tint, a narrow band at 4155 in the extreme violet end of the spectrum can usually be seen. This is strongest in stones in which the yellowish tint is distinct, and can then be quite intense. In such cases it is attended by other bands, of which one at 4785 is the most important. Weaker bands at 4650, 4520, 4350 and 4230 have been measured. It is interesting to note that the truly yellow diamonds which are sold as "fancy" stones do not show this series of bands, though the 4155 band may be visible.

In brown diamonds, and in greenish stones having a green fluorescence under ultra-violet light, a faint line in the blue-green region at 5040 can often be detected, sometimes attended by even fainter lines nearby. The 5040 line sometimes occurs at great strength in diamonds which have been turned green or brown by irradiation with atomic particles—but this has been found to depend upon the nature of the heat-treatment after irradiation, and cannot be relied upon as a diagnostic sign for treated diamonds.

The lines or bands in diamond mentioned above are now thought not to be caused by impurities in the stone, but to be structural in origin.

2 *Spodumene*

In the absorption-spectrum of spodumene the principal bands are at: 4380 (s.); 4320 (s.).

In the case of spodumene two sharp, narrow bands are visible in the violet. Their presence is sufficient for the identification of the yellowish-green spodumene. They are obscured in the case of hiddenite by the presence of chromium, and are not shown by kunzite.

3 *Tourmaline*

The absorption-spectrum of tourmaline is not a very satisfactory aid to its identification. As is the case with other minerals varying in tint, it changes in character with the colour.

Red and pink tourmalines exhibit a broad absorption band in the green, which appears to be variable in position, and two narrow bands at 4580 and 4510 in the blue. This absorption-spectrum bears some resemblance to the red chromium one except for the absence of the fine lines in the red, but these tourmalines do not seem to contain any trace of chromium.

In the case of the green and blue tourmalines the red end of the spectrum is cut off at about 6400, and a narrow band is visible at 4980 in the green as well as a weak, vague band at 4610 in the blue.

v Absorption-spectra of Synthetic Stones, Glasses and Doublets

a Synthetic Stones

1 *Synthetic Corundum*

The absorption-spectrum shown by synthetic ruby, being likewise due to chromium, is practically identical with that for the natural stone, except that it is more intense for an equal depth of tint. In the case of synthetic sapphire, though iron as well as titanium is used in the preparation, the iron appears to evaporate during the growth of the boule and no trace of the iron bands in the blue (the strongest of which, at 4500, can almost always be detected in natural stones) can be seen. The synthetic corundum of the alexandrite type, which has no counterpart in nature, owes its peculiar tint to vanadium, and in its absorption-spectrum shows a narrow line at 4750 in the blue, which is a useful criterion for recognizing it.

2 *Synthetic Spinel*

Synthetic blue spinels owe their colour to cobalt, and therefore show a characteristic absorption-spectrum, the chief feature of which lies in the three broad bands with centres at 6330 in the orange, 5800 in the yellow, and 5440 in the green; the intensity of these bands depends upon the depth of colour in the stones. Synthetic yellow and yellowish-green spinels show a vague band at 4480 and a narrow but stronger band at 4250 in the indigo-blue part of the spectrum; while some of the bluish types show these bands in addition to those due to cobalt. They are due to manganese, which, in the yellowish-green synthetic spinels, gives rise also to a strong green fluorescence under ultra-violet light.

3 *Synthetic Emerald*

The absorption-spectrum displayed by synthetic emerald is identical with that of natural emerald (*v.* above).

b Glasses

1 *Red Glass*

The absorption-spectrum of the red glasses depends, of course, upon the colouring agent. Often it is selenium, in which case the most usual feature is a broad band in the green, similar to that shown by red tourmaline.

2 *Blue Glass*

In the commonest kind of blue glass the colouring agent is cobalt, and in such kinds the absorption-spectrum is characteristic of this element with three broad bands centred near 6550 in the red, 5800 in the yellow and 5350 in the green. On the other hand, other blue glasses have no distinctive absorption-spectrum.

3 *Green Glass*

Some kinds of green glass owe their colour to chromium, and consequently show faint narrow bands in the red part of their absorption-spectrum; but most of them have no distinctive absorption-spectrum.

c Doublets

As would be expected, the absorption-spectrum of a doublet corresponds to its component parts. In the case of cheap doublets the top is a thin slice of almandine; the corresponding absorption-spectrum is consequently that pertaining to this gemstone, but is seen very faintly because of the thinness of the slice.

VIII

THE POLARIZING MICROSCOPE

At intervals throughout the preceding discussion of the optical properties of crystals mention has been made of the use of a microscope. In the scientific study of crystalline substances the polarizing microscope is one of the most useful instruments at one's disposal. Its full range of usefulness is somewhat restricted, when examining gemstones, by the nature of the material available, which usually may not be sectioned or crushed but must be examined as it stands; it has nevertheless important applications, of which an account is given in this chapter.

A. OBSERVATIONS IN ORDINARY LIGHT

The primary function of a microscope (though not necessarily the most important in the field of crystal optics) is that of a magnifying instrument. For this purpose a 'biological' type of instrument, with a fixed square stage, will suffice. Such an instrument, however, is unlikely to be equipped with polarizing appliances; these are found on the more elaborate 'petrological' types, with a rotating circular stage, primarily intended for the scientific study of minerals and rocks. A convenient instrument for the rapid examination of gemstones is the specially designed polarizing model by Rayner (plate II); it incorporates built-in illumination and correction for inversion of the image.

The combination of the lens-system of the objective and eyepiece affords a magnified image of an object placed on the stage. A hand lens being quite convenient for magnifications up to ten diameters, a suitable range for the microscope is from ten to one hundred diameters. Selected values in this range are obtained with interchangeable objectives used with the same eyepiece. The Rayner microscope incorporates three objectives, giving magnifications of 10, 25 and 60, which are parfocal at stage level in air and are interchanged by rotation of a drum. In the examination of a faceted stone of the most usual shape the simplest method is to lay the table facet on a glass slip and view the stone through the culet; alternatively, it may be held with the table facet uppermost by means of a small pellet of plasticine. If internal reflection from steeply inclined facets prevents examination near the girdle an immersion liquid must be used. A glass plate, held by hand over the stone with a drop of liquid between it and the plate, serves the purpose well for a rapid examination. A more stable arrangement is provided if the stone is placed with the table facet downwards in a glass immersion cell and just completely covered with the liquid. For qualitative observation it is not necessary to match the refractive index of the liquid closely to that of the stone; indeed, it is usually more convenient if the outlines of the facets remain distinctly visible, and for most stones the use of α-monobromonaphthalene (refractive index 1·655) will be found satisfactory. A stone which does not possess a pair of parallel facets should be viewed first through any pair which are nearly parallel. It may sometimes be necessary to turn the stone about; in air this is accomplished by holding it between the fingers, whilst for use in immersion liquids spring stone-holders constructed of stainless steel are available. A stone-holding attachment for the Rayner microscope is provided as an accessory. Illumination is controlled by adjustment of the sub-stage condenser and diaphragm if these are fitted. On occasions *dark ground illumination* may be preferred; the direct beam is stopped out and the stone is viewed against a dark background by light reflected on to it obliquely. The means for providing this kind of illumination vary with the type of instrument used, and may involve a change to a special sub-stage condenser or other fitting. In the Rayner microscope paraboloidal mirrors are permanently incorporated in the sub-stage system, and the illumination is changed by the insertion of a swing-in occluder. For observations in ordinary light some workers prefer a binocular microscope; binocular observation against a dark background is sometimes particularly effective. There are difficulties, however, in equipping a binocular instrument with satisfactory polarizing apparatus for use in the further procedures described later in this chapter.

I INCLUSIONS; GROWTH PHENOMENA

From the time of Sir David Brewster and H. C. Sorby, who worked in the earlier part of the nineteenth century, inclusions in crystals have been the object of study by many investigators. In the field of gemstones such investigations have recently received renewed impetus from the work particularly of H. Michel and E. Gübelin,[1] who have demonstrated

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[1] E. J. Gübelin, *Inclusions as a Means of Gemstone Identification.* Los Angeles, 1953.

their significance in several respects—the distinction of natural stones from synthetic products and imitations, the characterization of specimens from a particular locality, and the provision of information concerning paragenesis.

Many of the inclusions are of solid matter, frequently crystalline, though sometimes vitreous; included crystals may be well-formed with plane crystal faces (euhedral, idiomorphic) or they may be rounded and resorbed (anhedral, xenomorphic) or broken (plate IV, figs. 1, 2). The fine rutile needles (silk, p. 78) in sapphire and ruby, arranged at angles of 60° parallel to the prism faces (plate IV, fig. 3), are examples of such inclusions. They were formerly considered to be a certain indication that a stone was not synthetic. More recently, however, star rubies and star sapphires have been synthesized in Germany and the United States of America; the rutile needles are exsolved whilst Ti-containing boules prepared by the Verneuil process (p. 195) are held for some hours in an oxidizing atmosphere at a temperature of 1100°–1500° C. Other inclusions may be of liquid or of gas, occupying internal cavities in the host-crystal. These cavities are sometimes bounded by plane faces forming 'negative crystals' but more frequently they are irregular, sometimes very highly so. The liquid cannot be easily identified, but may for example be water, carbon dioxide, or a portion of the original mother liquor from which the host-crystal separated. Rarely two immiscible liquids may be present. Enclosed gas may form bubbles in the liquid and there may be a third phase present, a crystalline solid. Such three-phase inclusions occur typically in emerald from certain localities (plate IV, fig. 4); the crystals of the solid phase may appear rectangular or rhombic according to the angle of view. Inclusions of gas are frequent in natural glasses and in synthetic stones. Air bubbles, spherical or elongated, show a very wide black border, or may even be completely black as a result of total reflection; in crystalline material (plate V, fig. 2) they point indubitably to a synthetic origin.

A growing crystal is normally bounded by plane crystal faces; accession of materials of slightly varying composition, or brief interruptions in growth, may produce a zoned structure marked by slight colour differences or by layers of inclusions. These are seen under the microscope as a series of straight parallel striations which often meet other series sharply at an angle (plate V, fig. 1). The growth of a boule, however, in the Verneuil synthetic process (p. 196) is by accretion of layers on the curved upper surface, no plane crystal faces being developed. Synthetic corundum crystals are therefore marked by the presence of *curved* striations (plate V, fig. 2); such striations, however, do not appear often to be observed in spinel synthesized by the same process, nor do they occur in synthetic emeralds (which often display straight striations).

Solid inclusions may represent material the formation of which antedates the growth of the host-crystal (this is the more likely if the inclusions present a worn or broken appearance), or material which was crystallizing simultaneously with the host-crystal. The majority of euhedral crystalline inclusions, as well as many liquid and gaseous inclusions, probably belong to this stage. Thus of the euhedral inclusions described in diamond those of pyrope, enstatite, chrome-diopside, magnetite, ilmenite, zircon and diamond itself are all likely to have a close genetic relationship with the host (p. 286). Yet a further kind of inclusion, however, develops subsequently to the growth of the host, as a result of exsolution, chemical alteration or recrystallization. Here belong the phenomena of *feather* (p. 78) and *flag*—the development of cleavage-cracks or fractures within a crystal which enclose air, liquid, or subsequently introduced crystalline material.

Inclusions which have formed contemporaneously with the enclosing host may reflect closely the particular conditions of genesis typifying one locality. Thus inclusions of zircon are common in African diamonds but absent from Brazilian diamonds; in the latter, quartz is frequently found. Corundum from the three districts of Burma, Ceylon and Siam can often be localized by distinctive differences. Burmese crystals show a silk of fine rutile needles and abundant crystalline inclusions (plate V, fig. 4); crystals from Ceylon have a characteristic feather of liquid inclusions and amongst the solid inclusions those of metamict zircon (p. 356) are diagnostic; in specinens from Siam the feather has a distinctive hieroglyphic appearance and inclusions of opaque hexagonal crystals are also characteristic (plate V, fig. 3). A particular kind of inclusion may persist in several species from a given locality; metamict zircon, surrounded by a halo, is found not only in corundum from Ceylon, but also in spinel and garnet from the same region. On the other hand, an inclusion may be so typical of the species itself that it is found in almost all specimens whatever the locality; as examples we may note the bundles of fine hair-like inclusions in almost all demantoid garnets, and the tetrahedral negative crystals enclosing liquid with gas bubbles in fluorspar.

2 REFRACTIVE INDEX BY IMMERSION

The second important application of the microscope is to the determination of refractive index by immersion, particularly when by reason of the size, shape or other characteristics of the available material use cannot be made of a refractometer. The general procedure by which the refractive index of a solid is compared with that of an immersion-liquid of known index has already been described (p. 67). If the determination is carried out in ordinary light it relates to a single value of index. This is appropriate for isotropic substances—either non-crystalline such as obsidian or opal, or crystals belonging to the cubic system—and for cryptocrystalline aggregates such as minutely-crystalline chalcedony. To distinguish between different refractive indices of doubly-refracting crystals, however, it is necessary to make use of polarizing equipment, to the consideration of which we now pass.

B. PLANE-POLARIZED LIGHT

Various methods have been proposed for obtaining polarized light. Thus T. J. Seebeck found in 1813 that a plate of brown tourmaline cut parallel to the crystallographic axis and of sufficient thickness (p. 97) transmits only the extraordinary ray, the ordinary one being entirely absorbed within the plate. Another method was to employ a glass plate to reflect light at a certain critical angle. A most efficient method, which is still in use at the present day, is due to the invention of William Nicol. A rhomb of Iceland-spar (fig. 73), with a length about three times the breadth, is sliced as shown, and the halves are cemented together by means of Canada balsam. One ray, *ioo*, is totally reflected at the surface separating the mineral and the cement, and does not penetrate into the other half; while the other ray, *iee*, is transmitted with almost undiminished intensity. Such a rhomb is called a nicol prism after its inventor, or briefly, a nicol.

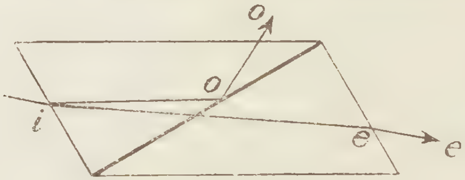


FIG. 73.—Nicol prism.

If one nicol be placed above another and their corresponding principal planes be at right angles, no light is transmitted through the pair. In the polarizing microscope one such nicol, called the polarizer, is placed below the stage, and the other, called the analyser, is either inserted in the body of the microscope or placed above the eyepiece.

The objection to the use of tourmaline plates for the production of polarized light is not merely that suitable pieces are comparatively uncommon, but also that even at the best the transmitted light is itself so much absorbed that a tourmaline plate is of service only if the source of illumination be strong. There are, however, certain organic birefringent substances which are strongly absorbent of one ray, even in very thin plates. So long ago as 1851 W. B. Herapath discovered that quinine iodosulphate ($4Qu\ .\ 3H_2SO_4\ .\ 2HI\ .\ I_4\ .\ 6H_2O$) crystallizes in hexagonal plates, which even when so thin as $\frac{1}{200}$ of an inch (0·127 mm.) completely absorb one ray and transmit the other with hardly any absorption. This material was named herapathite by W. K. von Haidinger. Since the plates lose their polarizing property if exposed to air or even if mounted in Canada balsam dissolved in xylol, it did not appear as if their remarkable dichroism was of the slightest practical importance. Indeed, the property had quite passed into oblivion until within recent years E. H. Land discovered an ingenious process of producing nitrocellulose sheets, in which the ultramicroscopic crystals of herapathite are correctly oriented, so that in effect they correspond to a single crystal plate. The ultramicroscopic crystals overlap, with consequent increase in the absorption, and the polaroid plates, as they are termed, are of a slightly smoky tint. It is a happy chance that these plates effectively polarize nearly the entire visible spectrum. In earlier types, polarization was incomplete over a part of the spectrum, but this defect was later overcome and polaroid plates are now often substituted for nicols in the polarizer and analyser of a polarizing microscope, and used in precisely the same way.

TWINKLING AND DICHROISM

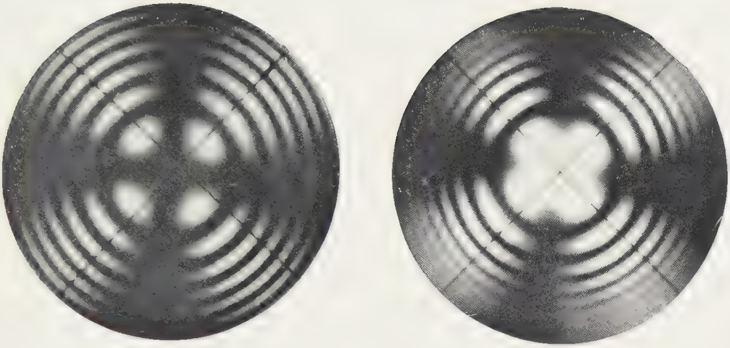
When the polarizer is inserted below the stage a plane-polarized beam impinges on the lower surface of an object on the stage. It is often arranged that the polarizer can be rotated in its mount; a spring catch then normally retains it in one position such that (in most English instruments) the transmitted beam vibrates 'east and west' (i.e. left and right of the observer). The transmission of such a beam through a crystal lying on the stage can be explained by consideration of the indicatrix. If the section of the indicatrix normal to the direction of transmission be a circle (as would be the case, for example, for a uniaxial crystal lying with its principal axis of symmetry parallel to the axis of the microscope) the plane-polarized beam is transmitted through the crystal without modification, and no change in appearance would be observable on rotation of the stage. If, however, the appropriate section be an ellipse the mode of transmission of the incident beam varies as the stage is rotated and the orientation of the ellipse in relation to the east–west vibration direction is changed. In general, the incident beam splits into two components vibrating respectively parallel to the major and minor axes of the elliptical section and travelling through the crystal with the appropriate corresponding velocities. Four times in a complete revolution of the stage, however, when one or other axis of the ellipse becomes parallel to the east–west vibration direction of the polarizer, a single plane-polarized beam is transmitted. With sufficiently large differences of refractive index the appearance of the object may thus change during rotation. With a gemstone in air no variation in this respect would be appreciable, but when viewing a stone immersed in a liquid the degree of relief (p. 67) corresponding to one vibration direction may be visibly different from that for the position at right angles. This change of relief on rotation in plane polarized light is known to mineralogists as 'twinkling'. In a coloured stone different velocities may correspond also to different absorptions and the consequent dichroism is demonstrated by a change of colour of the image on rotation. This method of examination, however, does not permit direct comparison of the two tints corresponding to the two directions of vibration, as does the dichroscope (p. 98), and weak dichroism may thus escape notice.

C. CROSSED NICOLS

For the next stage of examination the upper polarizing device, the analyser, is also introduced. Its vibration direction is set at right angles to that of the polarizer and the use of the two together is known as the position of 'crossed nicols'. With no object on the stage, the east–west vibrations transmitted by the polarizer are unable to pass the analyser and no light reaches the eye. If an optically isotropic object, such as a piece of glass or a cubic crystal, is placed on the stage the field still remains dark throughout a complete revolution. Should the transmitted beam, however, suffer double refraction on passing through the object, as in general happens with crystals other than those belonging to the cubic system, the effect is quite different.

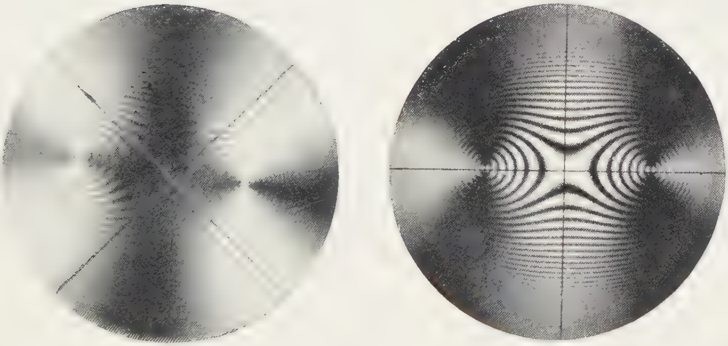
I EXTINCTION POSITIONS

We have seen (p. 119) that when the axes of the elliptical section of the indicatrix are inclined to the vibration direction of the polarizer the beam from the latter travels through the crystal as two components with different velocities. The slower of these thus lags behind the faster and on emergence has suffered a total retardation depending in magnitude upon the double refraction and upon the path-length. When the two



1. Uniaxial

2. Uniaxial
(*Circular Polarization*)



3. Biaxial
(*Crossed Brushes*)

4. Biaxial
(*Hyperbolic Brushes*)

VI. INTERFERENCE FIGURES

1. Charging the saws with oil and diamond powder
2. Inspecting a battery of sawing machines
3. Battery of polishing machines

VII. DIAMOND CUTTING

Reproduced by courtesy of I. J. Asscher) recombine on emergence there will, in general, be some component parallel to the vibration direction of the analyser; the intensity of this component will vary with the wave-length of the light considered, so that in white light an interference colour will be seen. This will be some colour from Newton's scale, familiar in such common phenomena as the colours of a soap-bubble, the hues of tarnished steel and the tints of a layer of oil floating on water. With small total retardations the colours are strong and deep-hued, but with the greater retardations corresponding to higher double refraction and to longer paths they pass to the pale colours of high orders, which are ultimately not appreciably different to the unaided eye from ordinary white light.

During a complete rotation of the stage four positions are reached in which the axes of the elliptical section assume parallelism with the vibration directions of the polarizer and analyser. In each of these positions only a single component is transmitted, and this is cut out by the analyser to give a position of darkness. These four positions of darkness during one rotation of the stage are called *extinction positions*. Clearly they must occur at settings of the stage 90° apart, between each of which illumination rises to a maximum brightness. This observation constitutes an exceedingly delicate test for double refraction. It serves, indeed, to reveal some degree of double refraction in many objects which should theoretically be singly refracting. Thus diamond sometimes shows double refraction, either localized around inclusions or more generally over the crystal. Double refraction can be induced in glass by strain and this appears to be the usual cause for such anomalous double refraction in supposedly isotropic crystals. Synthetic spinel containing an excess of alumina, for example (p. 202), shows strain due to the stress on the crystal structure, and synthetic emeralds (p. 205) may show anomalous double refraction in the direction of the optic axis. Such phenomena, however, are unlikely to cause confusion, since the extinction is usually patchy and not uniform throughout the stone, nor are the extinction positions sharp.

The mineralogist, working with crystals bounded by natural faces, makes considerable use of extinction positions to help determine the crystal symmetry. Thus a prismatic crystal of tourmaline, elongated parallel to the trigonal axis and lying flat on the stage, would extinguish when its length was parallel to the vibration direction of the polarizer or analyser (marked by the cross-wires in the eyepiece of a polarizing microscope). Such *straight* extinction suggests the presence of a symmetry element parallel to the length, and would not be likely to occur in many monoclinic or triclinic minerals (p. 34). Little use can be made of this procedure in the examination of gemstones, however, owing to the lack of any reliable co-ordination between the directions of cut facets and of natural crystal faces.

2 REFRACTIVE INDEX BY IMMERSION

Observation of extinction positions is a necessary preliminary to the accurate measurement of individual refractive indices of a doubly refracting stone by immersion. A stone is set in an extinction position between crossed nicols, the analyser is removed, and comparison is then made with the liquid for the particular plane-polarized disturbance which is transmitted. After turning the stage through 90° the second refractive index can likewise be compared with the liquid. It is particularly to be noted that *two refractive indices only are associated with a given direction of transmission*. Through confusion with the procedure of refractometry it is sometimes assumed that by rotating a stone over the polarizer a range of refractive indices can be passed through. This, of course, is fallacious; further values of refractive indices can be introduced only by *turning the stone over* on the stage so that a new direction of transmission is utilized.

D. CONVERGENT LIGHT

I INTERFERENCE FIGURES

Illumination thus far has been by means of a beam of parallel light. A further method of examination involves the use of a highly convergent beam, achieved by the introduction of an auxiliary condenser lens, any iris diaphragms in the substage being opened wide; the polarizer and analyser remain crossed as before. Components of the beam now traverse a doubly refracting stone in different directions, involving both different magnitudes of double refraction and different path lengths. On emergence the beam is highly divergent and it is brought back within the optical system by using an objective of fairly high power set close to the upper surface of the stone. The *interference figure* which we wish to examine is not formed in the same focus as the image of the stone. It may be viewed directly by removing the eyepiece from the tube, or, slightly magnified, by retaining the eyepiece and holding a hand lens a short distance above it. A petrological microscope is often fitted with an auxiliary lens (*Bertrand lens*) below the eyepiece which, in conjunction with the latter, produces a magnified image of the figure.

The nature of the figure seen depends upon the optical character of the stone, whether uniaxial or biaxial, and also upon the orientation of the stone in relationship to the axis of the microscope. With a uniaxial stone lying with its optic axis parallel to the axis of the microscope, as might be the case with a tabular ruby or a star sapphire, a black cross is seen (plate VI, fig. 1) surrounded by circular rings which are coloured in white light. On rotation of the stage this centred figure remains unchanged. If, however, the optic axis direction is inclined to the axis of the microscope the black cross is seen eccentrically in the field of view and its centre rotates as the stage is rotated. With increasing inclination the centre of the cross will lie outside the limit of the field, and with still greater inclination the figure becomes unrecognizable. It is characteristic of a uniaxial substance, however, that so long as the arms of the cross can be seen they remain parallel to the vibration directions of the polarizer and analyser during rotation of the stage. (The crosswires of the eyepiece are usually set parallel to the vibration directions of the polarizer and analyser, but in the photographs of plate VI are set at 45° thereto.)

If a biaxial substance be examined in the direction of the line bisecting the acute angle between the two optic axes, an interference figure will be seen which in particular positions of the stone with respect to the crossed nicols takes the forms illustrated in plate VI, figs. 3 and 4. As before, there is a series of rings which are coloured in white light, though they are no longer circular. Instead of an unchangeable cross there are a pair of black 'brushes' which in one position of the stage form a cross but which on rotation form hyperbolae. The brushes revolve about two points called the 'eyes'. The apparent distance apart of the eyes in the field of view is related to the magnitude of the optic axial angle $2V$ (p. 88). For small values of $2V$ the two eyes are well within the field of view and the hyperbolae are strongly curved; for larger values, the eyes cannot be included together within the field and the brushes assume only slight curvature. A quantitative application of these observations requires a detailed knowledge of the particular optical arrangement in use, but qualitatively they will serve, for example. to distinguish sinhalite (p. 351), with $2V - 56°$, from the olivine, $2V$ almost 90°, with which it has been confused.

The ease with which an interference figure can be observed depends very much upon the shape, size and nature of the stone under examination. With a large stone it may be difficult to transmit the necessary convergent beam. A cabochon stone or a small highly faceted stone, on the other hand, may in itself act as a form of condenser and materially assist the formation of a figure. So long as a portion of the figures described above can be seen it should be possible to determine whether the double refraction is uniaxial or biaxial. The optic sign may be determined with the help of a quartz wedge; with biaxial figures in particular, however, this necessitates a rather full understanding of crystal optics.

2 CIRCULAR POLARIZATION

Certain substances, of which quartz is a conspicuous example and in this respect unique among the gemstones, possess the property of rotating the plane of polarization of light which is transmitted parallel to the optic axis. The interference figure (plate VI, fig. 2) differs from the ordinary figure of a uniaxial stone. The cross does not penetrate to the centre of the field, which is coloured in white light. If a stone shows such a picture, it may safely be assumed to be quartz (p. 371). Between crossed nicols in parallel light a basal section of such a substance would show isotropic behaviour in remaining unchanged throughout a complete rotation of the stage but it would show a uniform interference colour instead of total darkness. This phenomenon is called circular polarization and substances showing it are described as optically active.

E. AUXILIARY APPARATUS

To conclude this chapter it may be noted that a microscope provides a convenient basic arrangement for use in conjunction with other apparatus, particularly when examining small stones or other material which is awkward to handle. A dichroscope in place of the eyepiece gives, as has been pointed out (p. 120), the important advantage over the simple use of the polarizer that the two fields are visible in juxtaposition for direct comparison. Spectroscopy also (p. 100) may conveniently be carried out with the direct vision instrument in place of the eyepiece. Many manufacturers supply a special fitting, with an adjustable slit for insertion in the tube slot of a polarizing microscope. The spectroscope available as an accessory to the Rayner gemmological microscope has a built-in adjustment for the slit and is used in conjunction with a special additional condenser.

IX

SPECIFIC GRAVITY

It is one of our earliest experiences that different objects of the same size have often markedly different weights; thus, there is a great difference between wood and iron, and still greater between wood and lead. It is usual to say that iron is heavier than wood, but the statement is misleading, because it would be possible by selecting a large enough piece of wood to find one at least as heavy as a particular piece of iron. We have, in fact, to compare equal volumes of the two substances, and all ambiguity is removed if we speak of relative density or specific gravity—the former term being usually applied to liquids and the latter to solids—instead of weight or heaviness. The density of water at 4° C. is taken as unity, that being the temperature at which it is highest; at other temperatures it is somewhat lower, as will be seen from the table in Part IV. The direct determination of the volume of an irregular solid presents almost insuperable difficulty; but, fortunately, for finding the specific gravity it is quite unnecessary to know the volume, as will be shown when we proceed to consider the methods in use.

The specific gravity of a stone is a character which is within narrow limits constant for each species, and is therefore very useful for discriminative purposes. It can be determined whatever be the shape of the stone, and whether it be transparent or not; but, on the other hand, the stone must be unmounted and free from the setting.

The methods for the determination of the specific gravity are of two kinds: in the first, a liquid is found of the same, or nearly the same, density as the stone; and in the second, weighings are made and the use of an accurate balance is required.

A. HEAVY LIQUIDS

Experiment tells us that a solid substance floats in a liquid denser than itself, sinks in one less dense, and remains suspended at any level in one of precisely the same density. If the stone be only slightly less dense than the liquid, it will rise to the surface; if it be just as slightly denser, it will as surely sink to the bottom, a physical fact which has added so much to the difficulty and danger of submarine manœuvring. If, then, we can find a liquid denser than the stone to be tested, and place the latter in it, the stone will float on the surface. If we take a liquid which is less dense than the stone and capable of mixing with the heavier liquid, and add it to the latter, drop by drop, gently stirring so as to ensure that the density of the combination is uniformly the same throughout, a stage is finally reached when the stone remains suspended at any level. It has now the same density as the liquid, and, if we find by some means this density, we know simultaneously the specific gravity of the stone. It should not be forgotten that certain gemstones, for instance opal and turquoise, are more or less porous. Prolonged immersion of such stones is therefore not wise, lest their appearance be in consequence adversely affected.

Various devices and methods are available for ascertaining the density of liquids—for instance, Westphal's balance; but, apart from the inconvenience attending such a determination, the density of all liquids is somewhat seriously affected by changes in the temperature. It is better therefore to measure at the time of the observation the refractive index instead, because, although each of these physical characters varies with the temperature, their ratio remains constant within the range of ordinary room-temperatures as regards the limits of accuracy required, and because the refractive index is easily and quickly measured by means of a refractometer. In the usual instance, where the liquid is a mixture of two components, the one dense and the other light, a table or diagram giving the relation between the density and the refractive index should be supplied or prepared beforehand.

If the determination of the specific gravity of a stone be required merely for discriminative purposes, a better alternative perhaps is to make direct comparison with fragments of substances of known specific gravity, which are termed indicators. If of two fragments, differing slightly in specific gravity, the one floats on the surface of a uniform column of liquid and the other lies at the bottom of the tube containing the liquid, we may be certain that the density of the liquid is intermediate between the two specific gravities. A precaution of this kind is wise in the case of a mixture of two liquids, because usually the lighter of them is much more volatile and the density of the liquid would tend to increase, and in any event the density is affected by change of temperature. The specific gravity of gemstones, on the other hand, as of solids in general, is not much affected by change of temperature.

A convenient alternative method of checking the density of a liquid is to use an instrument known as a hydrometer, which works on the principle that the extent to which a partially immersed body sinks is immediately related to the density of the liquid. Modern hydrometers are made of sealed glass tubes with a narrow stem above, containing the graduated scale. The tube is loaded inside according to the range for which it is required. The instrument is simple to use; it is merely placed in the liquid and the corresponding density read off from the scale.

A possibly more convenient variation of this method is not to attempt to find a solution of exactly the same specific gravity as the stone under test, but to form a diffusion column, so that the density increases progressively with the depth. If the stone under test floats in such a column at a certain level intermediate between two fragments of known specific gravity, its specific gravity may be found by elementary interpolation. In order to form a column of this kind the lighter liquid should be carefully dripped upon the heavier. Natural diffusion gives the most perfect column, but, as it is rather a lengthy process, it may be conveniently quickened by gently shaking the tube; the column thus formed gives results sufficiently accurate for discriminative purposes.

If constant use be made of the specific gravity test, it would obviously be advantageous to have ready a series of stoppered tubes, containing liquids of differing density. The number used would, of course, depend upon the particular requirements, and could be varied at will. If the test be only occasionally applied, three or four tubes might be amply sufficient. On the other hand, any one having constantly to test stones might increase the number, so as to have available a series, in shallow steps, of grades of density, and might find it useful to have at hand fragments of all the principal species, in order that direct comparison may be made.

We may now pass to the discussion of the use and respective advantages of the various liquids which have been employed for the quick determination of the specific gravity of gemstones.

I CLERICI SOLUTION

A most convenient liquid, which covers the whole range of gemstones, is the one known as Clerici solution after its discoverer.[1] It is a mixture

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[1] Enrico Clerici, 'Preparazone di liquidi per la separazone dei minerali,' *Atti della Reale Accademia dei Lincei*, 1907, vol. 16, pp. 187–95. A study of the liquid's preparation and properties is given by Helen E. Vassar, 'Clerici solution for mineral separation by gravity,' *The American Mineralogist*, 1925, vol. 10, pp. 123–5; and by C. J. Payne, L. Franklin and B. W. Anderson, 'The use of Clerici solution for density determinations,' *The Gemmologist*, 1936, vol. 5, pp. 274–9.

of thallium malonate, $CH_2(COOTl)_2$, and thallium formate, HCOOTl, which is a clear liquid with only a slightly amber tint, and has at ordinary room-temperatures a density of 4·25, increasing with the temperature until near the boiling-point of water, 90–100° C., it will float pyrites, which has a specific gravity of about 5. The liquid is miscible with water in any quantity, and can readily be reconcentrated by careful heating over a low gas-flame or on a sand-bath. Like all thallium compounds Clerici solution is poisonous, and should be used with reasonable care. Although it can be safely used for all gemstones except those that are porous, it cannot be applied to minerals indiscriminately, because, especially if hot, it will attack certain of them, for instance metallic oxides.

Clerici solution is obtainable ready made, together with a series of glass indicators of known specific gravity. It may, however, be prepared from thallium carbonate, Tl_2CO_3, by mixing equal quantities of the salt with the corresponding amounts of malonic acid and formic acid; 111 grams of the former acid and 115 grams of the latter will each neutralize 500 grams of the carbonate, and 1 kilogram of thallium carbonate will yield about 300 c.c. of Clerici solution. An alternative method is to mix equal quantities of thallium malonate and thallium formate; the difference in the result of the two methods is too slight to be of practical consequence.

If it be desired to achieve the density at which the stone under test is in perfect suspension and floats at any level, it is wise to dilute not with pure water but with a still more dilute solution so as to vary the density gently. When the correct density is attained, the refractive index of the solution should be read off by means of a refractometer; the corresponding density may be determined from the table in Part IV. Although Clerici solution, being a mixture and not a definite compound, may have slightly different physical constants in different preparations, the difference is too small to have any material effect on the figures in the table.

2 METHYLENE IODIDE

A liquid, which is very convenient to use, although less wide in its range than Clerici solution, is methylene iodide, CH_2I_2, which has already been recommended for its high refraction. It has, when pure, a density of 3·324 at 16° C.[1] It may be diluted rapidly with benzol, the density of which is 0·88, or more gradually with bromoform, density

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[1] The density of methylene iodide decreases ·0022 for a rise of 1° C. and vice versa.

1. Beryl crystal. 2. Figure of Buddha (cut from a sapphire). 3. Sapphire crystal. 4. Sapphire. 5. Blue beryl. 6. Yellow sapphire. 7. Morganite. 8. Golden beryl. 9. Aquamarine. 10. Emerald. 11. Diamond. 12. Heliodor. 13. Ruby crystal. 14. Emerald crystals (in matrix)

VIII. GEMSTONES

2·88. When fresh, methylene iodide has only a slight tinge of yellow, but it rapidly darkens on exposure to light owing to the liberation of iodine, which is in a colloidal form and cannot be removed by filtration. The bottle containing it should therefore be blackened or covered in some way to exclude the light, but the liquid may easily be cleared by shaking it up with fragments of copper, tin or other substances with which the iodine combines to form an iodide removable by filtration. Mercury has been suggested, but is not satisfactory, because a small quantity may be dissolved and afterwards precipitated on to the stone under test, carrying it down to the bottom of the tube. Caustic potash (potassium hydroxide) also might be used, but again is not without objection, since water separates out and floats on the surface, and it is necessary to employ a special apparatus, which will allow the clear methylene iodide to be drawn off underneath.

In fig. 74 three cut stones, a quartz (*a*), a beryl (*b*) and a tourmaline (*c*), are shown floating in a diffusion column of methylene iodide and benzol. Although the beryl has only a slightly higher specific gravity than the quartz, 2·69 as compared with 2·65, it floats at a perceptibly lower level. These three species, which are occasionally found as yellow stones of very similar tint, can thus be readily distinguished by the specific gravity test.

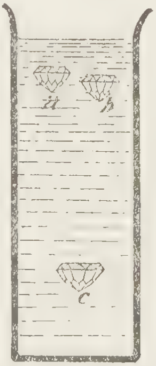

Fig. 74.—Stones of different specific gravity floating in a diffusion column of heavy liquid.

In a table in Part IV the relation is given between the refractive index and the density of a mixture of methylene iodide and benzol, in case the suspension method of ascertaining the specific gravity of a stone be used.

The density of methylene iodide may be increased by dissolving iodine and iodoform in it; the saturated solution has a density of 3·6 and will float topaz, the specific gravity of which is 3·55. Unfortunately the liquid is then so dark as to be almost opaque, and it is, moreover, very viscous. It is useful to discriminate diamond, with a specific gravity 3·52, from the brilliant colourless zircon, with a specific gravity about 4·7, with which, apart from a test for double refraction by the apparent doubling of the edges at the back of the stone when viewed through the table facet (p. 82) or for hardness, it may easily be confused. It is easy to see whether the stone floats as it would do if it be a diamond. To recover a stone which has sunk, the only course is to pour the liquid off into another tube, because it is far too dark for the stone to be seen.

3 BROMOFORM

The use of bromoform, $CHBr_3$, was first proposed by Schroeder van der Kolk[1] as a convenient means of separating the constituent minerals of sands. At ordinary room-temperatures it has a density of 2·88 and a refractive index of 1·588. It is decomposed on exposure to light and air. It may be diluted with alcohol or benzol, but preferably with the former owing to the more convenient concentration; if distilled water be added to the solution, the alcohol combines with it and separates on the top, and the denser bromoform may be drawn off in a separating funnel, any excess moisture being evaporated off in a desiccator.

Mention should also be made of acetylene tetrabromide, or tetrabromoethane, $C_2H_2Br_4$, which may be used in the same way as bromoform and has a higher density, 2·964 at 20° C. It is miscible in all proportions with alcohol.

A number of other heavy liquids have been recommended. Sonstadt (or Thoulet) solution is a saturated aqueous solution of potassium iodide and mercuric iodide, with a density of 3·196 at room-temperature. Klein solution is an aqueous solution of cadmium borotungstate, density 3·55. Retgers's salt is silver-thallium nitrate, which melts at a temperature of 75° C. to a liquid of density 4·6. None of these, however, has been much used for work with gemstones and only Clerici solution and methylene iodide can be recommended for general application. On account of its cheapness, bromoform is especially useful for gemstones of specific gravity below 2·9.

B. DIRECT WEIGHING

The balance which is necessary in both the methods described under this head should be capable of giving results accurate to milligrams, that is, the thousandth part of a gram, and, consistent with that restriction, the beam may be as short as possible, so as to give rapid swings and thus shorten the time taken in the observations. A good assay balance answers the purpose admirably. Instead of the ordinary form of chemical balance, Westphal's form or Joly's spring-balance may be employed. Weighings are made more quickly, but are not so accurate.

In refined physical work the practice known as double-weighing is employed to obviate any slight error that there may be in the suspension of the balance. A counterpoise, which is heavier than anything to be weighed, is placed in one pan, and weighed. The counterpoise is retained

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[1] Jacobus Lodewijk Conradus Schroeder van der Kolk (1865–1905), 'Beitrag zur Kartirung der quartären Sande,' *Neues Jahrb.*, 1895, I, pp. 272–6.

in its pan throughout the whole course of the weighings. Any substance, the weight of which is to be found, is placed in the other pan, and weights added till the balance swings truly again. The difference between the two sets of weights evidently gives the weight of the substance. Balances, however, are so accurately constructed that for testing purposes such refined precautions are not really necessary.

It is immaterial in what notation the weighings be made, so long as the same be used throughout, and the unit may be either the gram or the carat. Inasmuch as jewellers use carat-weights in the ordinary course of business, they would naturally prefer the latter unit; students in physical laboratories, on the other hand, would find the balances supplied with gram-weights.

I HYDROSTATIC WEIGHING

The principle of this method is very simple. The stone, the specific gravity of which is required, is first weighed in air and then when immersed in water. If W and W' be these weights respectively, then $W - W'$ is evidently the weight of the water displaced by the stone and having therefore the same volume as it, and the specific gravity is therefore equal to $W/(W - W')$.

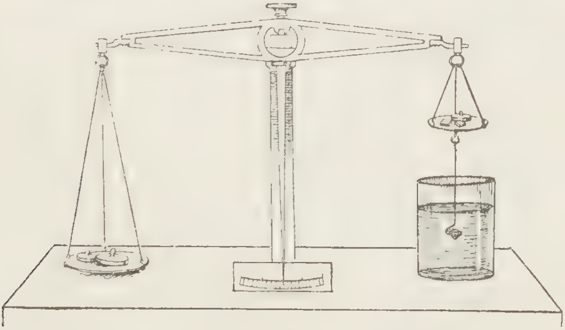

FIG. 75.—Hydrostatic weighing.

If the method of double-weighing had been adopted, the formula would be slightly altered. Thus, suppose that c corresponds to the counterpoise, w and w' to the stone weighed in air and water respectively; then we have $W = c - w$ and $W' = c - w'$, and therefore the specific gravity is equal to $(c - w)/(w' - w)$.

Some precautions are necessary in practice to ensure an accurate result. A balance intended for specific gravity work is provided with an auxiliary pan (fig. 75), which hangs high enough up to permit of the stone being suspended underneath; but such refinement is unnecessary, since the glass vessel may equally well be supported upon a small stool, spanning the pan on one side, or even upon a short, flat ruler, resting upon temporary supports, such as match-boxes. The weight of anything used for the suspension must, of course, be determined and subtracted from the weight found for the stone, both when in air and when in water. A piece of fine silk is often used for suspending the stone in water, but its use is not advised, because the water tends to creep up it and the error thus introduced affects the first place of decimals in the case of a 1-carat stone, the value being too high. A piece of brass wire, shaped into a cage, is much to be preferred. If the same cage be habitually used, its weight in air and when immersed in water to the customary extent in such determinations should be found once for all.

Care must also be taken to remove all air-bubbles which cling to the stone or the cage; their presence would tend to make the value too low. The surface-tension of water, which makes it cling to the wire, prevents the balance swinging freely, and renders it difficult to obtain a weighing correct to a milligram when the wire dips into water. This difficulty may be overcome by substituting a liquid such as toluol, which has a much smaller surface-tension. An alternative liquid with low surface-tension that has been recommended is ethylene dibromide, $C_2H_4Br_2$, which has a density of 2·184 at 18° C., decreasing or increasing 0·002 with a rise or fall in the temperature. The density, which may vary slightly, may readily be checked by using the liquid in the case of quartz, which is known to have accurately 2·651 as the value of its specific gravity; the density will therefore be $2{\cdot}651 \times (W - W')\ W$, where W and W' are the weights of the piece of quartz in air and liquid respectively.

As has been stated above, the density of water at 4° C. is taken as unity, and it is therefore necessary to multiply the value obtained by the density of the liquid, whatever it be, at the temperature of the observation. In the table in Part IV are given the densities of water and toluol at ordinary room-temperatures. It will be noticed that a correct reading of the temperature is far more important in the case of toluol.

Examples of the hydrostatic method of determining specific gravity, in water and toluol—

(*a*) Water: quartz (colourless).

Weight (in carats) of stone in—

air	43·432
water[1]	27·059
difference	16·373

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[1] Allowance has been made for the weight of the stirrup.

Specific gravity $= \frac{43{\cdot}432}{16{\cdot}373} = 2{\cdot}653\ (2{\cdot}6527)$.

Corrected for the temperature, 14·2° C., the value is 2·651 (2·6507).

(*b*) Toluol: topaz (colourless).

Weight (in carats) of stone in—

air	20·318
toluol [1]	15·377
difference	4·941

Specific gravity $= \frac{20{\cdot}318}{4{\cdot}941} \times 0{\cdot}8665$ (density of toluol at 17·2° C.) $= 3{\cdot}563$.

2 PYCNOMETER, OR SPECIFIC-GRAVITY BOTTLE

The specific-gravity bottle is merely one with a fairly long neck on which a horizontal mark has been scratched, and which is closed by a ground-glass stopper. The pycnometer is a refined variety of the specific-gravity bottle. The best form for the present purpose has two openings: the larger is intended for the insertion of the stone and the water, and is closed by a stopper through which a thermometer passes, while the other, which is exceedingly narrow, is closed by a stopper fitting on the outside, and is graduated to facilitate the determination of the height of the water in it.

The stone is weighed as in the previous method. The bottle is then weighed, and filled with water up to the mark and weighed again. The stone is now introduced into the bottle, and the surplus water removed with blotting-paper or otherwise until it is at the same level as before, and the bottle with its contents is weighed. Let W be the weight of the stone, w the weight of the bottle, W' the weight of the bottle and the water contained in it, and W'' the weight of the bottle when containing the stone and the water. Then $W' - w$ is the weight of the water filling the bottle up to the mark, and $W'' - w - W$ is the reduced weight of water after the stone has been inserted; the difference, $W + W' - W''$, is the weight of the water displaced. The specific gravity is therefore $W/(W + W' - W'')$. As in the previous method, this value must be multiplied by the density of the liquid at the temperature of the experiment. If the method of double-weighing be adopted, the formula will be slightly modified.

Of the above methods, that of heavy liquids, as it is usually termed, is by far the quickest and the most convenient for stones of ordinary size, and by its aid a value may be obtained which is accurate to the second place of decimals, sufficing for a discriminative test. The method is

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[1] Allowance has been made for the weight of the stirrup.

applicable no matter how small the stone may be, and, indeed, for very small stones it is the only trustworthy method; for large stones it is inconvenient, not only because of the large quantity of liquid required, but also on account of the difficulty in estimating the position of the centre of gravity of the stone, when comparison is made with indicators. A negative determination may be of value, especially if attention be paid to the rate at which the stone falls through the liquid; the denser the stone the faster it sinks, but the rate depends also upon the shape of the stone.

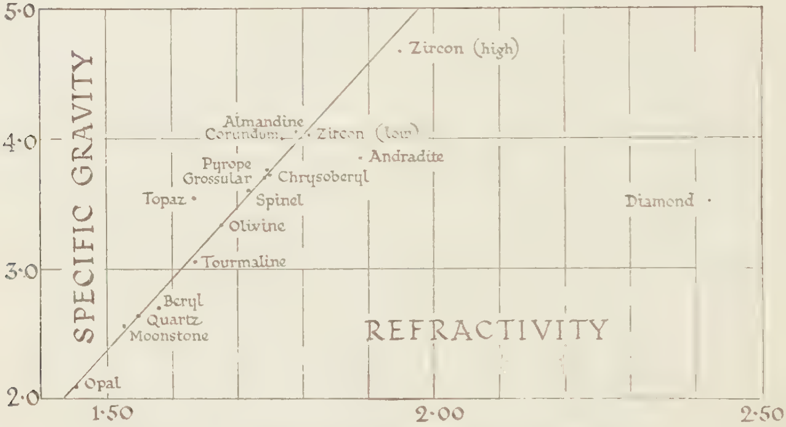

FIG. 76.—Refractivity-specific gravity diagram.

Hydrostatic weighing is always available, unless the stone be very small, but the necessary weighings occupy considerable time. The third method is intended primarily for powdered substances, and is not recommended for cut stones, unless there happen to be a number of tiny ones which are known to be of exactly the same kind.

The specific gravities of the gemstones are given in the table in Part IV.

Before leaving the subject of specific gravity we will consider the ratio between it and the refractivity of the principal gemstones. The latter constant is interpreted as the arithmetical mean of the three principal refractive indices of a biaxial stone, $\frac{1}{3}(\alpha + \beta + \gamma)$, which becomes $\frac{1}{3}(2\omega + \epsilon)$ for a uniaxial stone, and the refractive index itself for a singly-refractive stone. In the diagram shown in fig. 76 these two constants have been plotted for the principal gemstones. The horizontal axis gives the refractivity and the vertical axis the specific gravity. Each point therefore represents the two constants for the corresponding species.

Many of the points are seen to lie on or near a straight line, or in other words for the corresponding species the ratio between the refractivity and the specific gravity remains nearly constant. There are three conspicuous exceptions to this simple relation: diamond, in which the specific gravity is relatively low for the refractivity; andradite, in which the disparity is in the same direction, though not so large; and topaz, in which on the contrary the specific gravity is higher than might be expected from the refractivity. That there is some departure from a linear relation in the diagram is only to be expected, since it is known that the simple law connecting the refractive index and the density proposed by Gladstone and Dale [1] for liquids does not hold for the solid state.

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[1] John Hall Gladstone, F.R.S. (1827–1902), and Rev. T. Pelham Dale (1821–93), 'Researches on the refraction, dispersion, and sensitiveness of liquids,' *Phil. Trans. Roy. Soc.*, 1864, vol. 153, p. 337.

X

OTHER PHYSICAL PROPERTIES

A. HARDNESS AND CLEAVABILITY

The hardness of a stone is the resistance which its surface sets up when an attempt is made to scratch it with another stone or other object, and is a measure of the cohesion of its atomic structure. Every possessor of a diamond ring is aware that diamond easily scratches window-glass, even if avoiding indelible evidence of the fact. If other stones be tried, it will be found that they also scratch window-glass, but not so readily, and, if the experiment be extended, it will be found that topaz scratches window-glass, but is scratched by corundum, which in its turn yields to the all-powerful diamond. There is therefore considerable variation in the capacity of precious stones to resist abrasion, or, as it is usually termed, in their hardness. In order to simplify the method of expressing this character, the mineralogist Friedrich Mohs, at the beginning of last century, devised the following arbitrary scale, which is still in general use:

SCALE OF HARDNESS

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

For practical purposes it is useful to remember that the finger-nail will scratch gypsum and softer substances, and that ordinary window-glass is slightly softer than feldspar, while a steel knife is slightly harder, and a hardened file is still harder, approaching quartz in hardness, and will easily scratch glass. Since the various species of precious stones are at least as hard as quartz, the file will easily discriminate them from the soft paste stones which imitate them in appearance, and before the introduction of the refractometer for use with cut stones this was the only test in general use in the jewellery trade.

By saying that a stone has hardness 7 we mean that it will not scratch quartz and quartz will not scratch it. The numbers in the scale indicate merely the order of hardness, and have no quantitative significance whatever. This is an important point about which mistakes have often been made. We must not, for instance, suppose that diamond (10) has twice the hardness of apatite (5) or that topaz and spinel (8) have 80 per cent of the hardness of diamond. As a matter of fact, the interval between diamond and corundum is immensely greater than that between corundum and talc, the softest of mineral substances. Intermediate degrees of hardness are expressed by fractions. The number $8\frac{1}{2}$ for chrysoberyl means that it will scratch topaz about as easily as it itself is scratched by corundum. Pyrope garnet is slightly harder than quartz (7) and slightly softer than beryl ($7\frac{1}{2}$); its hardness is therefore expressed by the symbol $7\frac{1}{4}$.

Delicate tests have shown that all crystallized substances have a more or less grained type of structure, and the hardness for the same stone varies more or less in different directions. The variation is similar to what every possessor of a pocket-knife well knows by experience in the case of wood; much less effort is demanded to cut along than across the grain. Kyanite is unique among minerals in variation of hardness, since it ranges from 5 to 7, and a specimen can therefore be scratched by a knife in some directions but not in others. In most substances, however, the range is too small to be perceptible by ordinary tests.

Lapidaries have found that specimens of the same species from different localities may vary in the ease with which they may be cut and polished. Thus diamonds from Borneo and New South Wales are said to be so distinctly harder than those from South Africa and elsewhere that some difficulty is experienced in cutting them, and, while Ceylon sapphires are found to be harder than rubies, Kashmir sapphires are softer. Although the hardness, like the other physical characters, may vary from crystal to crystal of the same species owing to a change in the chemical composition due to the isomorphous replacement of one element by another, this does not explain the differences experienced by lapidaries, since such variation would be far too small to be detected by such rough-and-ready tests. Another character which we may term toughness is superimposed. It results from twinning, which may be of a repetitive nature, or from other interruptions in the continuity of the intimate structure. The twinning of diamond, which often cannot easily be detected, accounts for the variation in the labour involved in cutting different stones. A similar explanation may be advanced in the case of ruby and sapphire.

Attempts have been made to measure the hardness of minerals by different methods, depending upon various principles such as scratching, grinding, boring and piercing, or deforming the surface. The most marked feature of these attempts is the remarkable and relatively enormous discrepancy between the results. The obvious conclusion is that the several methods are not comparable with one another, and that cohesion is an exceedingly complex property.

Although of little use for discriminative purposes, hardness is a character of fundamental importance in a stone intended for ornamental wear, since upon it depends the durability of its polish and brilliance. Ordinary dust is composed largely of grains of sand, which is quartz in a minute form, and a gemstone should therefore be at least as hard as 7. Paste imitations are only slightly harder than 5, and consequently, as experience shows, their polish does not survive a few weeks' constant wear, apart from the deleterious effect upon the surface of impurities in the air.

Hardness does serve as a convenient test for distinguishing quartz and harder gemstones from their paste imitations, since the latter yield so readily to the file. It is a useful test for diamond, because, being so very much harder than any other gemstone, it will score a scratch on glass which is much deeper than one produced by ruby or sapphire.

Hardness is not a test which can be advised for general application, because there is obvious risk of damaging a stone. If the stone be set, it should preferably be removed from the setting and the test applied to the girdle, because any scratch made there would be effectively concealed by the setting when the stone was replaced. Any mark should be rubbed to ensure that it be not due to powder from the abrasive agent, since confusion may often arise in this way when the two substances are of nearly equal hardness. If for any reason it be desired to determine the hardness of a cut stone, it is better to attempt to scratch a plate with it and not to scratch it with a point, because the former plan is far less likely to damage the stone. For convenience in testing the hardness of minerals so-called hardness-points, which are fragments of known hardness mounted in small handles, are obtainable; for reasons that have already been emphasized their use for cut stones, except with extreme caution, is strongly to be deprecated.

The degrees of hardness of the gemstones are given in the table in Part IV.

The result of the grained structure of crystals, to which reference was made above, is that the cohesion may be very slight in certain directions defined by the intimate arrangement of the constituent atoms, while considerable in all others; or in other words even very hard minerals may be readily split or cleaved.[1] The property of cleavage in fact characterizes many mineral species of widely differing degrees of hardness. Mica, which is a very soft mineral with a degree of hardness of only about 2, readily splits into sheets even thinner than paper. Diamond, the hardest of minerals, can be split in four directions parallel to the faces of the regular octahedron, a property which is used by the lapidary for shaping a stone previous to cutting it, and a great saving of labour. A highly characteristic property of topaz is the ease with which it will cleave at right angles to the vertical crystallographic axis. Plagioclase feldspar has two directions of cleavage that are nearly at right angles, and spodumene will easily split in two directions mutually inclined at an angle of about 87°. It has already been remarked (p. 44), that owing to the effect of repeated twinning crystals of certain gemstones, corundum being a well-known example, possess planes of parting. This property differs fron cleavage in that splitting is possible only along planes separating the twinned lamellae.

In Part IV is given a list of gemstones distinguished by possessing planes of cleavage or of parting.

It must be remembered that all stones are more or less brittle and can be fractured by a sufficiently violent blow, but the irregular surface of a fracture, with usually conchoidal (shell-shaped) markings, cannot be mistaken for the well defined surface produced by a cleavage. The cleavage is by no means induced with equal facility in the species mentioned above. A considerable effort is required to split diamond, as, indeed, may be gauged from the fact that in distant days the resistance to a blow from a hammer was understood to be a sure test for discriminating the hardest of gemstones. Topaz, on the other hand, splits so easily that incipient cracks in the shape of 'feathers' may be started if a stone be knocked against a hard object. Kunzite, the beautiful lilac variety of spodumene, has such an easy cleavage that some care is needed to prevent its development during cutting. Euclase, too, is a gemstone that is extremely difficult to cut because of its easy cleavage.

B. ELECTRICAL AND LUMINESCENT CHARACTERS

The definite orientation of the intimate structure of crystals leads in many instances to attributes which vary with the direction and may be

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[1] It is one of the peculiarities of the English language that two words, differing in origin and opposed in meaning, have assumed an identical form: cleave. As used here in the sense of split it appears to have come through Old German from the Greek γλύφω (hollow out, engrave); but derived from another Old German source it means adhere. Cleavage, however, is used only in one sense: splitting.

revealed by the electrical properties. If a tourmaline crystal be heated, it becomes charged with electricity, and, since it is at the same time a bad conductor, static charges of opposite sign develop at the two ends, and persist, though reversed in sign, after cooling. Tourmalines, if exhibited in an internally illuminated case, may thereby become warmed and will collect to themselves an undue share of the fine dust in the surrounding air. Topaz shows similar characters, but not to the same extent. Quartz, if heated, will show static charges of opposite sign on different sides, but the phenomenon may be masked by intimate twinning and the consequent overlapping of the contrary areas. These electrical charges may be detected in the cut stones. The property is known as pyroelectricity, from the Greek word, πῦρ (fire).

The most convenient method for discovering whether a stone after warming possesses static charges is that devised by Kundt. A powder consisting of a mixture of red lead and sulphur is placed in a bellows contrivance and blown through a sieve at one end on to the stone. Owing to the friction thus produced the particles become electrified—red lead positively and sulphur negatively—and are attracted by the charges of opposing sign, and the corresponding areas on the stone will be betrayed by the colour of the dust clinging to them. The powder must be kept dry, since otherwise a chemical reaction may be set up, leading to the formation of lead sulphide, recognizable by its black colour. As an alternative, the use of sulphur coloured red with carmine for the negative element, and yellow lycopodium for the positive element has been suggested.

If diamond, topaz and tourmaline be rubbed with a cloth, the frictional electricity thus developed is strong enough to attract tiny fragments of paper, the electricity being positive. Amber when treated in a similar way develops considerable negative electricity. The property which amber possesses of becoming electrified when rubbed with a cloth has long been known; indeed, it is from the Greek word for amber, ἤλεκτρον, that our word electricity has been derived.

The electrical characters, although of considerable interest to the student, especially because of the confirmatory light that they throw upon the directional properties of certain gemstones, are, on account of their limited application and difficulty of test, of little practical value for the discrimination of gemstones.

Certain gemstones, as well as many other substances, have the remarkable property of emitting in response to the stimulus of rays which have fallen upon them, others which differ in wave-length from the former. If the emitted rays lie within the range of the visible spectrum, although the rays that excited them lie without that range, we have the phenomenon of luminescence, which bears differing names according to the character of the phenomenon.

If a substance glow when stimulated by the heat rays lying beyond the red end of the visible spectrum, the phenomenon is known as thermoluminescence, and as triboluminescence when the heat results from friction. The flashes emitted when two flints are rubbed together exemplify the latter effect. The term thermoluminescence is derived from the Greek word, *φέρμη* (heat). Triboluminescence is derived from the Greek word, *τρὶβος* (rubbing).

When the stimulus is due to the rays lying beyond the violet end of the visible spectrum, the phenomenon is called fluorescence, if it is strictly simultaneous with the stimulus, and phosphorescence, if it endures for at least a perceptible period after the stimulus has been cut off. (This phenomenon is quite different from the luminosity of phosphorus in the dark, which results from a slow oxidation of the material.) Sir John Herschel, in the course of a study of a solution of sulphate of quinine was the first to describe fluorescence in 1845, but the explanation of this remarkable phenomenon was advanced by Sir G. G. Stokes in 1852 as the result of an elaborate investigation of this luminescent character in the minerals, fluor, autunite, apatite, aragonite, chrysoberyl, kyanite and topaz, and various organic substances, including sulphate of quinine. It was Stokes, also, who first put forward the term fluorescence: 'I am almost inclined to coin a word and call the appearance *fluorescence*, from fluor-spar, as the analogous term *opalescence* is derived from the name of a mineral.'

Phosphorescence is not a common property of gemstones. Many diamonds will glow in the dark after exposure to sunlight; and both diamond and kunzite phosphoresce after excitation by rays beyond the violet end of the visible spectrum, even by those so short in wave-length as radium emanations. It may be noted that glass does not phosphoresce when similarly excited, and is, moreover, opaque to X-rays; diamond, on the other hand, is transparent to them, and can thus be distinguished from its paste imitations.

The best fluorescent effects are produced by rays which are not much shorter in wave-length than visible violet rays, and the most useful source is the spectrum emitted by incandescent mercury vapour. This spectrum includes several strong lines: namely, a doublet in the yellow (5791, 5770 Å), a line in the green (5461 Å), and two lines in the violet (4358, 4047 Å), all being in the visible spectrum; a strong line (3650 Å) just on the limit of vision and three lines of short wave-length (3341, 3132, 3125 Å). The violet colour of the mercury lamp, which with the neon light is nowadays extensively used for decorative illumination, represents the resultant effect of the strong visible lines on the eye. Since so vivid a light would mask the fluorescence produced, it is necessary to cut off these rays. Fortunately, there is available a dark glass, known as Wood's glass filter, which absorbs practically the whole of the visible spectrum, while freely transmitting the ultra-violet rays. The case containing the mercury-vapour lamp is therefore provided with a window which is blocked by a piece of dark glass, and is placed in a suitable dark cabinet so that ordinary light can be excluded. When the lamp is switched on, nothing can be seen until fluorescent material is placed in the field covered by the ultra-violet rays, when it will glow with its appropriate colour, which like the colour due to absorption is the resultant of the parts of the visible spectrum which are emitted. Research has shown that the response of substances to ultra-violet radiation may vary with the wave-length of the incident rays. Radiation with the strong line at 3650 Å, as described above, generally gives the most spectacular results. These, however, may not be so useful for diagnosis as those obtained with 'short-wave' ultra-violet rays. An electric discharge through low-pressure mercury vapour, contained in a bulb of quartz or special glass, allows radiation to pass down to about 1800 Å. Most of the visible spectrum, and the longer ultra-violet rays, are absorbed by a special glass filter (Chance OX 7) which passes much of the strong emission at 2537 Å. It should not be overlooked that ultra-violet rays have penetrative power, and caution should be exercised not to expose the eyes, and, indeed, the body generally to the direct rays for more than a moment or two.

It must be remembered that fluorescence is not an essential property of any of the gemstones; even fluor, which displays it so beautifully and to which it owes its name, does not always display it. Certain varieties of gemstones, however, are invariably characterized by it. For instance, in 'long-wave' ultra-violet light ruby and ruby-red spinel and the corresponding synthetic material possess a striking red fluorescence; indeed, as was pointed out above (pp. 104, 112), their absorption-spectra contain several lines in the red, which are due to fluorescence. Many diamonds display a sky-blue fluorescence, though the intensity varies from faint to very brilliant; a few fluoresce yellow or greenish. Diamonds are so inconsistent in their response, however, that photography of a multi-stone diamond brooch has been suggested as a means of identification of the particular piece of jewellery. Other gemstones which fluoresce in ultra-violet rays, the resultant tints being given in brackets, are: kunzite (flesh-pink), opal (bluish or yellowish), turquoise (green), fluor (violet), some zircon (mustard), danburite (sky-blue), some willemite (bright green), and some emerald (red). In addition to these gemstones fluorescence is displayed by certain organic products. Both pale and dark amber show a powder-blue bloom, especially on fresh surfaces. Pearls, both native and cultured, fluoresce with colours that depend upon the place where the corresponding oysters lived; the sky-blue fluorescence of oriental and Australian pearls is particularly pleasing, but any difference between natural and cultured pearl is insufficient to aid identification.

The effects produced by the 'short-wave' lamp are usually weaker and the fluorescence may be a different colour. Some gems which are inert in the longer wave-length may fluoresce strongly; benitoite, for example, shows a bright blue glow and may thus be readily distinguished from sapphire which is inert. Colourless synthetic spinels which show only a dim glow in the longer wave-length radiation exhibit a bright blue or violet fluorescence in the shorter wave-lengths; coloured synthetic spinels behave similarly, though the fluorescent effect is modified by the body colour of the stone.

Since the sun's radiation is strong in the ultra-violet rays, the appearance of a fluorescent stone in bright sunlight is the resultant effect of the colours due to the absorption and to the fluorescence which characterizes it. Ruby owes much of its beauty to its fluorescence. The property is noticeable in daylight in some opal and amber and in most fluor.

Fluorescent effects are also produced by X-rays and by cathode rays, which are still shorter in wave-length than the ultra-violet rays. Those resulting from X-rays are on the whole not so intense, but, on the other hand, some stones are excited by them which do not respond to the ultra-violet rays, so that they are more general in their application. It is clear that for diagnostic purposes the best course is to examine the fluorescent effects afforded by a stone in both ranges of the ultra-violet rays and in X-rays. The cathode rays resemble X-rays in the character of their fluorescent effects, but the intensity is much stronger.

The lengthening of the wave-length of rays is a familiar phenomenon. Ordinary window-glass is transparent to the visible rays, but opaque to the infra-red rays, which are mainly responsible for the heat effects. When the sun, for example, shines on a greenhouse, the light-rays pass through the glass, but the infra-red rays are excluded. The former have their wave-lengths increased by reflection from the interior, and the resulting infra-red rays are trapped by the glass. The temperature of the interior is thereby raised; additional warmth arises from the heat-rays impinging upon the exterior, and reaches the interior by conduction.

Piezoelectricity, from the Greek word *πιέζω*, press, and electricity, though of no discriminative value has proved of immense importance for exact maintenance of wave-length in broadcasting and for extremely accurate timekeeping (p. 373). It may be considered to be the converse of pyroelectricity, since the charges set up correspond to those occurring when the appropriate crystal contracts on cooling. Tourmaline and quartz display piezoelectricity.

Part II

TECHNOLOGY AND HISTORY

XI

UNIT OF WEIGHT

The unit used for weighing precious stones is the carat, defined as one fifth of a gram (200 milligrams), which became the legal standard in Great Britain on 1 April 1914; it was at first and frequently still is known as the metric carat, in order to distinguish it from the older weights previously in use. For pearls a smaller unit is used, namely, the pearl-grain, which is one fourth of a carat (50 milligrams). In both instances weighings are not carried beyond the second place of decimals, the third place being ignored, however high the digit may be. For some gemstones, which may often be of a relatively large size, the gram, or for still larger stones the kilogram, or even the ounce or the pound may be used instead.

The cost of a gemstone is computed from the price per carat by simple multiplication of the price by the weight, but, with the exception of the less commonly used ornamental stones, the price per carat tends to rise with the size of the stone, and in some instances very rapidly.

A much more complex method is in use for pearls. The price is quoted by the base, as it is termed, the pearls being graded according to their quality, and the cost of a bunch of pearls is given by the formula, $p \, . \, \Sigma \frac{w^2}{n}$, where n is the number of pearls in each grade, w their total weight in pearl-grains, p the base price and Σ the sum. In practice the mean weight is first found, and then multiplied by the weight, and the product by the price per base. To make the method clearer the following examples are given:

(*a*) A bunch of pearls consists of 44 strings, containing 1529 pearls, which are grouped in two sizes, and the base price is 10*s.* 0*d.*

Strings	n	Carats	w	$\frac{w}{n}$	$\frac{w^2}{n}$
26	827	143·62	574·48	0·69	396·39
18	702	63·70	254·80	0·36	91·72
44	1529	207·32	829·28		488·11

The total product, 488·11, multiplied by the base price gives £244 1*s.* 1*d.* as the value of the bunch.

(*b*) A parcel of 64 button pearls is grouped in four sizes, and the base price is 4*s.* 0*d.*

n	Carats	w	$\frac{w}{n}$	$\frac{w^2}{n}$
5	7·80	31·20	6·24	194·68
10	13·53	54·12	5·41	292·78
17	16·75	67·00	3·94	263·98
32	24·61	98·44	3·07	302·21
64	62·69	250·76		1053·65

The total product, 1053·65, multiplied by the base price gives £240 14*s.* 7*d.* as the value of the parcel.

In figs. 77 and 78 are illustrated respectively the exact sizes of diamonds, when cut as brilliants, and of pearls, when spherical in shape, corresponding to certain weights in carats and pearl-grains respectively.

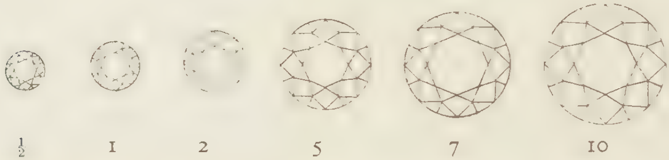

FIG. 77.—Sizes of diamond brilliants of various weights in carats.

The sizes of other gemstones will vary from those of diamond, since the weight is the product of the volume and the specific gravity. In the case of stones cut in the same regular shape—in this instance, brilliant form—the volume is proportional to the cube of the diameter. Consequently

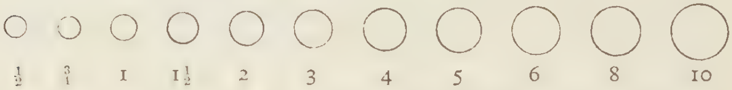

FIG. 78.—Sizes of round pearls of various weights in pearl-grains.

the diameter of another brilliant-cut gemstone bears to that of a diamond of the same weight the proportion of the cube root of the inverse ratio of the corresponding specific gravities. Quartz, having a low specific gravity, would be perceptibly larger than a diamond of equal weight, whereas zircon with a higher specific gravity would be smaller.

Stencil gauges are available for determining the approximate weight of diamonds, when brilliant-cut, and of pearls, which in both instances may be mounted. A somewhat more accurate method, involving the use of callipers, was devised by Charles Moe; the weight is found by reference to a table, and allowance can be made for variations from the ideal shape.

It is remarkable that, despite the high prices which precious stones have for centuries commanded and the consequent importance of ascertaining and recording the weight in such a way that no disputes could arise, no definite standard should have been fixed for the carat-weight until it was based upon the metric system of weights. Previously not only was the unit different at the various trade centres in the world, but in the course of time it had also tended to alter at the several centres. Until the introduction of the metric carat the carat in London was assumed to weigh 3·1683 grains (0·20530 gram), 1 ounce troy (480 grains) being defined as equivalent to $151\frac{1}{2}$ carats. It was, however, not a legal weight and no recognized standard existed, although in fact a weight called the carat has been in use in England since Norman times. The legal weight for precious stones in the United Kingdom was the same as for the precious metals—the ounce troy. The approximate equivalents, in relation to the gram, of the carat in use at the principal trade centres before the introduction of the metric carat were as follows: Florence, 0·19720; Madrid, 0·20539; Berlin, 0·20544; Amsterdam, 0·20570; Lisbon, 0·20575; Frankfort-on-Main, 0·20577; Vienna, 0·20613; Venice, 0·20700; Madras, 0·20735. The carat did, indeed, at that time vary from 0·1885 gram to 0·2135 gram.

Another curious feature was that the sub-multiples of the carat were expressed not in decimals but in successive powers of the half down to the sixty-fourth, and the intermediate weight (under a carat) of a stone was given in a series of fractions, e.g. $\frac{1}{2}$, $\frac{1}{8}$, $\frac{1}{64}$; in the case of diamonds an unreduced fraction to the base 64 was substituted, e.g. $\frac{40}{64}$. All these eccentricities disappeared upon the introduction of the metric carat, and the normal decimal notation, limited to the second place, came into use.

The systems of weights obtaining in various parts of the world were originally based upon the seeds of some plant, common in the particular region, which were nearly uniform in size and weight. In Europe the smallest unit of weight seems to have been the barley grain. Since precious stones originally reached Europe from the East, for which reason so many of the finer varieties were dubbed 'oriental', we must look there for the plant that provided the seeds which were at the beginning used to weigh precious stones. It happens that the locust-tree, *Ceratonia siliqua*, which is common in the countries bordering the Mediterranean, produces seeds that have an average weight[1] nearly

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[1] Sir Arthur H. Church gives the average weight as $3\frac{1}{6}$ grains, that is, 0·205 gram (*Precious Stones*, London, 1924, p. 71). L. J. Spencer records a slightly lower value for the average weight of 50 seeds taken at random, namely, 0·197

equal to the carat and very probably formed the original unit. Moreover, the word carat is derived from the Greek name for the plant, κεράτιον, which means little horn and refers to the shape of the pods.

Some writers[1] have suggested with less probability a different origin for the carat, and have supposed it to be derived from *kuara*, the native name for the coral-tree, *Erythrina corallodendron*. The average weight of its seeds is about the same as for the locust-tree.[2]

It is of interest to note that with the Greeks the κεράτιον, like its equivalent with the Romans, the siliqua, was a weight, and at the time of the Emperor Constantine twenty-four of them went to the golden solidus. This is probably the origin of the other modern meaning of the word carat, as a measure of the fineness of a gold alloy.[3]

It was not until late in the last century that the desirability of basing the carat-weight upon some definite standard received general recognition. In 1871 the Chambre Syndicale de la Bijouterie in Paris advanced the proposal that the carat-weight should be made exactly 0·205 gram. This proposal was approved by the Chambre Syndicale des Négociants en Diamants et Pierres in 1877, also in Paris, but failed to gain support elsewhere. Matters thus remained at a standstill until 1907, when the so-called metric carat of 200 milligrams was proposed by the Comité International des Poids et Mesures and accepted by the Quatrième Conférence Générale des Poids et Mesures at Paris.

In view of the place where the metric carat originated it is not surprising that France took the lead in endeavouring to secure international

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gram (*Mineralogical Magazine*, 1910, vol. XV, p. 324). J. H. Coste found 40 normal seeds to vary from 0·120 to 0·268 gram, the arithmetical average being 0·2004 gram, with a probable variation of 0·0235 gram, and the median and modal averages, obtained from consideration of the distribution of weights in the series, being 0·207 gram and 0·204 gram respectively, and found further the variation in the humidity hardly to affect the weight (*Nature*, 1917, vol. 99, p. 185).

[1] For example, L. Feuchtwanger says: 'The gems are sold by weight, as carat and grain. One carat is equal to four grains, and forty-four carats are equal to one ounce. The name carat is derived from the word *kuara*, the coral-tree (erythrina), the red pods of which, when dry, were formerly used for weighing gold dust, and each of them weighs four grains, which is equal to one carat.' (*A Popular Treatise on Gems*, New York, 1859, p. 181.) It may be noted that he probably meant to say that 144 (not 44) carats are equal to one ounce.

[2] L. J. Spencer found the weight to be the same, namely, 0·197 gram (loc. cit.).

[3] For example, in 18-carat gold there are 18 parts of the precious metal to 6 parts of base metals.

agreement for its adoption as the legal weight for precious stones, the French Government through their Ambassadors approaching the countries that were interested. In Great Britain the Board of Trade thereupon issued a circular letter about the proposal to the leading members of the jewellery trade throughout the country, but few of them even took the trouble to reply and among those few opinion was divided, the majority being opposed to any change of the carat in use. The explanation of this apathy is not far to seek: the retail traders experienced no difficulty with the existing system, since the same unit was in use throughout the country, and, although the dealers would benefit by the adoption of an international unit, some may have been repelled by the necessity for new weights and for the revision of the weights of their stocks during the transitional period. The Board of Trade came therefore to the conclusion that the time was not ripe, and in due course the French Ambassador was informed that for the time being no action would be taken, but that the question would be considered afresh if the principal European countries were to adopt the new standard.

So in Great Britain the matter rested for a few years; but soon, inspired by their more enlightened members, the jewellery traders themselves began to move. At the instigation of their Education Committee the National Association of Goldsmiths at their annual conference at Scarborough in July 1912 passed a resolution recommending the adoption of the metric carat as the legal weight for precious stones. The London Wholesale Jewellers' and Allied Trades' Association passed a similar resolution in February 1913. Both resolutions were transmitted to the Board of Trade. It is true that the Joint Committee of the Jewellers' and Silversmiths' Association were very lukewarm at their meeting in October 1912, and passed a non-committal resolution; but the reason why a stronger line was not taken seems to have been that many of the members were not directly interested. However, by October 1913 the Board of Trade were sufficiently convinced of the support of the jewellery trade to take the necessary action for an Order in Council, which under the provisions of the Weights and Measures (Metric System) Act of 1897 alone was required to legalize the metric carat. The Order did not come into force until 1 April 1914, leaving traders sufficient time to acquire new weights and to revise the weights of their stock. As will be seen below, within the limits of legislative exigencies the four leading countries in the precious stone trade—Great Britain, Holland, Belgium and the United States—legalized the metric carat simultaneously. In the introduction of this long-needed reform

Great Britain was therefore well to the fore.[1] Its adoption in South Africa was delayed until 1923 by the first world war. It is worth mentioning that the use of the metric carat is permissive and not compulsory in Great Britain; anyone, if so perversely inclined, might substitute for it in his business any other of the legal units of weight.

The metric carat was legalized in the following countries in the years stated: 1908, Spain; 1909, Japan, Switzerland; 1910, Bulgaria, Denmark, Italy, Norway; 1911, Holland, Portugal, Rumania, Sweden; 1912, France; 1913, Belgium, U.S.A.; 1914, Great Britain; 1922, Austria, Ireland, Mexico, Russia (U.S.S.R.), Siam; 1923, South Africa; 1930, Czechoslovakia, Poland. Although Holland passed the necessary legislation in 1910, it brought it into operation in 1913 simultaneously with Belgium. In some countries—for instance, Germany—it has apparently not been considered necessary to legalize separately the metric carat, because it may be used under the metric system of weights and measures already in force. The metric carat is now therefore the international unit for gemstones in universal acceptance.

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[1] For further details of the introduction of the metric carat into Great Britain see 'Great Britain and the Metric Carat,' by G. F. Herbert Smith, *Watchmaker & Jeweller, Silversmith & Optician*, 1940, pp. 117–18.

XII

TREATMENT OF STONES

Although many of the species of gemstones have been endowed by nature with brilliant, lustrous faces, and display scintillating reflections from their surfaces, yet their form is never such as can reveal to full perfection the optical properties upon which their charm depends. Apart from the irregularities of shape due to interference with the growth, the natural faces are rarely perfect, unless the crystals be very small; they are often more or less stepped or pitted, and, if more than an inch or so across, are obviously uneven. The crystals may, moreover, have been broken either through some movement of the rock in which they were formed, or in the course of extraction from the matrix in which they lay; or they may have been roughened by attrition against stones of equal or greater hardness, worn by the prolonged action of water, or etched by solvents. Beautiful octahedra of diamond or spinel have been mounted without further embellishment, but even their appearance might have been much improved at the lapidary's hands. The fashioning of gemstones is only the first stage in their treatment if they are intended for use in jewellery. The second and final stage is to provide means for holding them. Sometimes the form chosen for the setting will dictate the shape that is imparted to the stone to be fixed in it.

A. HISTORY AND FORMS

In ancient times little or no attempt was made to shape gemstones, and all that was done to improve their appearance was to smooth or polish the natural form. Since they were coveted merely for their surface coloration and not for the internal glow, which was at that date unknown, and were usually strung and worn as a pendant or in a necklace, there was felt to be no need to constrain their shape to certain proportions. In such exceptional instances as the High-priest's Breastplate (p. 221) what the artificer almost certainly did was to select the stone nearest in colour and dimensions to the requirements and fit the setting to it, and not contrariwise adapt the stone to the setting, as he would do to-day. Notable instances of ancient jewels which still retain their original form are provided by the historical stones, the Black Prince's Ruby and the Timur Ruby, which are accordingly the most interesting objects among the British Crown Jewels.

i Cabochons

By far the oldest of the modes of cutting in use at the present day is the rounded shape known as cabochon, from a French word, which is itself derived from the Latin *cabo*, meaning a head. So long ago as the days of the Emperors in ancient Rome the softer gemstones were often treated in this manner. Such stones were supposed to be beneficial to those suffering from myopia (short-sightedness), the reason being that transparent stones, if cut in the shape of a hollow cabochon, formed concave lenses. Nero, for instance, was said to have used an emerald when watching the gladiatorial combats.[1] This style of cutting was long a favourite for coloured stones, such as emerald, ruby, sapphire and garnet, but is no longer used except for star-stones and cat's-eyes and generally for opaque, semi-opaque and imperfect stones. The crimson garnet, which was at one time known by the name carbuncle, was so systematically cut in this form that the word has come to mean a red garnet cabochon-cut. It was a popular brooch-stone in the middle of last century, but does not accord with the taste of the present day.

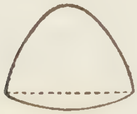

FIG. 79.—Double (convex) cabochon.

FIG. 80.—Simple cabochon.

FIG. 81.—Double (cavo-convez) cabochon.

When the cabochon form extends all over the stone so that it becomes a bead, it is still popular among Oriental races. The beads are drilled through the centre, threaded together, and worn as necklaces. The native lapidaries often improve the colour of pale stones by lining the hole with an appropriate paint.

The cabochon form may be of three different kinds, which merge into one another. In the first (fig. 79), the convex cabochon, both the upper and the under sides of the stone are curved, the curvature always having the same sense though varying, perhaps considerably, in degree. Moon-

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[1] 'Nero princeps gladiatorum pugnas spectabat smaragdo.' Pliny, loc. cit., book 37, ch. 5. It is possible that the emerald was used as a mirror.

stones and star-stones, when cut in this form, are set with the more pointed end uppermost for the better revelation of the optical effect. A ruby or a sapphire, on the other hand, which is deep in colour, may, when cut as a convex cabochon, be set the other way, because the light will more readily enter the stone through the blunter end and be more completely reflected from the other end with a consequent enrichment of the glow emitted from the stone. Opals are always more pointed on the exposed end, but the slope varies considerably; they are generally cut steeply for mounting in rings. Chrysoberyl cat's-eyes are cut with curved bases, both to enhance the colour and to maintain the weight.

With the flattening of the blunt end the convex cabochon passes into the second kind (fig. 80), the simple cabochon, in which the under side is plane. This is the form which is commonly used for quartz cat's-eyes and sometimes for carbuncles. A stone, cut as a simple cabochon, is always set with the plane side underneath.

With the reversal of the curvature of the under surface the simple cabochon passes into the third kind (fig. 81), the concavo-convex cabochon, in which the stone is hollowed out underneath and the sense of the curvature changes abruptly at the girdle. This style is reserved for dark stones, such as deep-coloured carbuncles, which, if cut in a thicker form, would show very little colour. A piece of tinfoil is often placed in the hollow in order to increase the reflection of light and thus to heighten the colour effect.

ii Faceted Stones

In early days it was supposed that diamond because of its extreme hardness could not be cut, and up to the fifteenth century all that was done was to remove the gum-like skin which usually disfigured the Indian stones and to polish the natural faces or surfaces. The widely disseminated story that the grinding of facets on diamonds by means of metal discs charged with diamond powder was invented by a Louis de Berquem, of Bruges, has been disproved by Henri Polak, who was unable to trace his existence, and it is probable that the practice originated in India.[1] In the beginning lapidaries merely evinced their victory over this stubborn material by grinding diamonds into divers fantastic shapes, and failed to realize what a potent weapon was now at their disposal for enhancing the beauty of diamonds.

Lapidaries in India either independently made the discovery of the possibility of faceting diamonds, or learned of it; for the traveller,

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[1] See A. Selwyn, *The Retail Jeweller's Handbook*. London, 1945, p. 210.

Tavernier,[1] when visiting the country in 1665, found a large number of diamond cutters actively employed. They had no greater range of knowledge and skill than the European workers. If the diamond were perfectly clear, they contented themselves with polishing the natural faces. If, however, it contained flaws or specks, they covered it with numerous small facets, haphazardly placed. So much was this their practice that a defective stone was betrayed by its multitude of facets. The original shape of the stone was left unaltered, and no attempt was made to improve the symmetry. As will appear in the chapter on Historical Stones, India did produce lapidaries with the skill and patience required for engraving diamonds.

For a long time little further progress was made in fashioning diamonds, and even in the latter half of the sixteenth century the only regular forms known were the diamond-point and the diamond-table.[2] As may be surmised from an appreciation of the crystal form of diamond, both were based upon the regular octahedron. The diamond-point consisted merely of its natural faces, ground to regular shape if necessary, and for a long time was employed for the small diamonds set to embellish large coloured stones in rings. It may be assumed that the crystals selected approximated very closely to the perfect octahedron, and consequently the labour involved in shaping them was comparatively slight. It must have been far otherwise in the case of the diamond-table. In the first place the stones used must necessarily have been much larger, because otherwise it would have been scarcely worth while shaping them. The diamond-table (fig. 82) was derived from the regular octahedron by grinding down one corner until the facet thus formed was in width half the central square section, the sides being adjusted until they were truly at right angles to one another; the opposite corner was only slightly ground until blunted. The labour and time consumed in grinding away about one-sixteenth of the total mass of the stone with the very primitive appliances then available must have been prodigious. It may

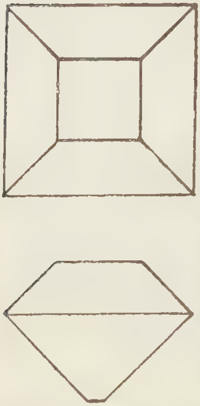

FIG. 82.—Diamond table: (1) crown, (2) side.

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[1] Jean Baptiste Tavernier (1605–89).

[2] 'Adamas. 1, Acuminatus, figurae quadragulae. Ein Diemant punckt. 2, Quadratus planus. Ein Diemant tafel.' Johannes Kentman. (Collection of tracts by him and Conrad Gesner under general title *De omni rerum fossilium genere, etc.*, 1565, p. 47.)

be noted that sometimes only the upper part (crown) was formed, the part below the girdle being left unfaceted.

I ROSES

The rose form, which in its most symmetrical shape consists of a hemisphere covered with twenty-four, regularly-disposed, triangular facets and a flat base (fig. 83), is said to have been invented by Cardinal Mazarin,[1] but probably he was the first to have diamonds of any considerable size cut in this form. There can be little doubt that the rose form of cutting originated in India, and was introduced into Europe by the Venetians. At the present day only small diamonds are cut as roses.

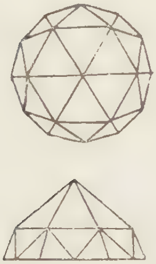

FIG. 83.—Dutch rose: (1) crown, (2) side.

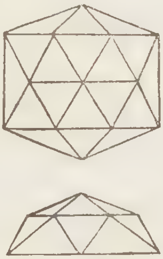

FIG. 84.—Half Dutch rose: (1) crown, (2) side.

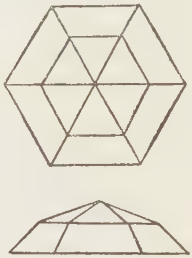

FIG. 85.—Antwerp rose: (1) crown, (2) side.

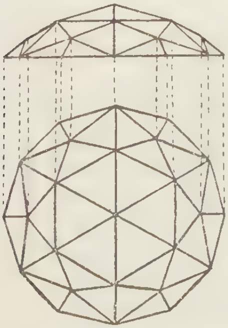

FIG. 86.—Double Dutch rose.

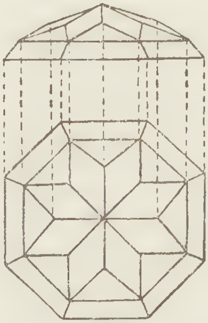

FIG. 87.—Cross-rose.

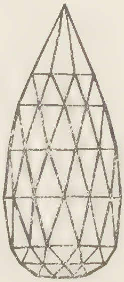

FIG. 88.—Briolette

Some six or seven variants of the rose form of cutting have been used. They are alike in the flatness of the base and the hexagonal (sixfold)

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[1] Jules Mazarin (1602–61), Cardinal 1640, succeeded Richelieu in 1642 as first minister of France and continued in that office until his death.

symmetry of the arrangement of the facets as viewed from above. The Dutch rose (fig. 83) is the typical form with twenty-four triangular facets; the Half Dutch rose (fig. 84) and the Antwerp rose (fig. 85) have fewer, namely, sixteen and twelve respectively; while the Double Dutch rose (fig. 86) has as many as thirty-six. The facets are usually triangular in shape, but in one form—the Cross-rose (fig. 87)—they are mostly quadrilateral.

The briolette (pear-shaped drop, fig. 88) may be considered to be a modified double-rose. It possesses the characteristic triangular facets. Briolette, or sometimes written brillolette, is used in French for a pear-shaped diamond.

2 BRILLIANTS

A few more years passed away, and at length in the closing years of the seventeenth century diamond came into its own when Peruzzi[1] introduced the brilliant form of cutting, and revealed for the first time its amazing fire. So obviously and markedly superior was this form of cutting diamond to all others that upon its discovery the possessors of large rose stones had them re-cut in the new shape despite the considerable diminution in weight that resulted. Except for comparatively minor, though not unimportant, alterations in detail this style of cutting has ever since remained essentially the standard form for diamond, and consequently the word brilliant has come to be commonly employed to denote a diamond cut in this style.

FIG. 89.—Brilliant: (1) crown, (2) side, (3) base.

The brilliant form (fig. 89) is derived from the old table-cut, the number of facets being considerably increased but the general shape not much altered. In the original form the outline of the girdle, as the edge separating the upper and lower portions of the stone is termed, was a more or less pronounced oblong with rounded corners. More recently

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[1] Vincenti (or Vincenzio) Peruzzi (or Peruggi), a lapidary of Venice, where at that date some of the best work in art was done.

the square shape became popular, and to-day the ideal arrangement of the facets is octagonal in symmetry, the girdle being circular in contour. The number and arrangement of the facets, which still remain much as they were at the beginnng of the use of this form of cutting, are as follows:

CROWN (UPPER, FRONT OR TOP)

No.	Name	Shape	Angular Position	
			ϕ	ρ
1	Table	8-sided, large	0°	0°
8	Star	3-sided, small	22°	22°
4	Bezel, Templet	4-sided, large	0°	46°
4	Quoin, Lozenge	4-sided, large	45°	46°
8	Cross, Skew	3-sided, small	17°	50°
8	Skill	3-sided, small	28°	50°

The total number of facets in the crown, as the upper or front portion of the stone is termed, is thirty-three. It is more usual nowadays to combine the quoins with the bezels and the skill- with the cross facets, thus making eight bezels and sixteen cross facets. The star facets surround the table, and the cross and skill facets form the boundary of the girdle. The names used for the facets appear to have been originally suggested by their shape or position, but the skill facets were so termed because of the difficulty experienced by lapidaries in placing them correctly.

PAVILION (LOWER, BACK OR BASE)

No.	Name	Shape	Angular Position	
			ϕ	ρ
1	Culet	8-sided, small	0°	0°
4	Pavilion	5-sided, large	0°	39°
4	Quoin	5-sided, large	45°	39°
8	Cross	3-sided, small	17°	44°
8	Skill	3-sided, small	28°	44°

The total number of facets in the pavilion, as the lower or back portion or base of the stone is termed, is twenty-five. Here again it is more usual to combine the similar facets so that there are eight pavilions and sixteen cross facets. The small culet, which is sometimes omitted, is surrounded by the large pavilion facets, and the cross and skill facets meet the similar facets of the crown in the girdle. In a brilliant-cut stone the total number of facets is fifty-eight.

A somewhat different terminology was used in the diamond works at Brighton. The facets are: on the top, the table, stars (eight triangular), kites (eight quadrilateral), and halves (sixteen triangular); on the bottom, the collet, pentagons (eight five-sided), and halves (sixteen triangular). Bezels are the second lot of four facets formed on the top to make up the kites when finished; similarly on the bottom side pavilions are the corresponding set of four facets, which complete the number of pentagons.

The angular position is determined by the point in which the normal to the corresponding facet meets a sphere from the centre of which the normals are imagined to be drawn. ϕ corresponds to the longitude on the terrestrial globe and ρ to the latitude, except that it is measured from the pole and not the equator. The latter co-ordinate remains constant for all the facets of the same kind, but the former must be added to or subtracted from multiples of a right angle to give the positions of the remainder of the group. Thus ϕ is: for the templets, 0°, 90°, 180° and 270°; for the star facets, 22°, 68°, 112°, 158°, 202°, 248°, 292° and 338°.

It will be observed that, if a stone be accurately cut, a bezel has a pavilion nearly parallel to it, and similarly with regard to the upper and lower cross facets. The contour of the girdle is usually square or circular in shape, but it is often varied to suit particular purposes; thus the contour may be rhombic (diamond or lozenge) in shape, or it may be less symmetrical as in pendeloques (drop-stones), in which the relative size of the facets is adjusted to fit the distorted shape. In recent years a rectangular form has been favoured for the girdle.

The appearance of a large diamond is greatly improved by an increase in the number of facets. An additional set of eight star facets in such instances often surrounds the culet. In the largest cut diamond, the Star of Africa, which is the chief product of the Cullinan stone (p. 241), still a further set of eight facets has been added, bringing the total up to seventy-four.

The brilliant form of cutting was discovered by trial and error, and experience has taught lapidaries that, in order to secure the finest optical effects, certain proportions are required in the stones. The crown should be one-half as deep as the pavilion, and therefore have one-third the depth of the stone. The width of the table should be slightly less than half the total width of the stone. The culet, on the other hand, should be quite small, having not more than one-sixth of the width of the table; its real purpose is in fact to avoid the danger of the point splintering. An old rule was to remove the top corner of the regular octahedron by sawing or grinding so that $\frac{5}{18}$ of the diagonal was removed, and similarly to remove the bottom corner so that $\frac{1}{18}$ of the diagonal was removed; in fig. 90 we have $At = \frac{5}{18} AA'$ and $A'c = \frac{1}{18} AA'$, whence we see that Ot, which is $\frac{2}{9} AA'$, is one-half Oc, which is $\frac{4}{9} AA'$. Then $\frac{TT'}{CC'} = \frac{Tt}{Cc} = \frac{At}{A'c} = 5$, and the width of the culet is one fifth of the table. Marcel Tolkowsky, who made a study of the proportions necessary for a perfect brilliant, arrived at slightly different figures: taking 100 units as the width of the girdle, the height of the crown above the girdle should be 16·2 and the depth of the culet below it 43·1, the total height of the stone being 59·3, and the width of the table should be 53; the corresponding angles of the bezels and pavilions with regard to the table and culet are 34° 25′ and 40° 46′ respectively.

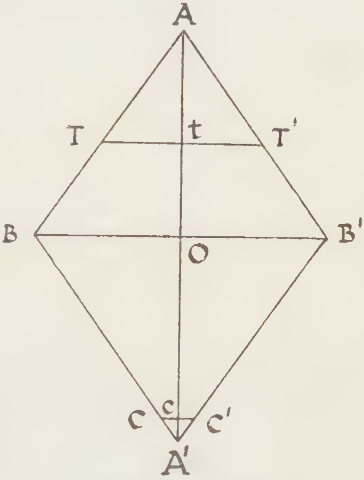

FIG. 90.—Reduction from octahedron to brilliant.

The girdle should be as thin as is compatible with a strength sufficient for the avoidance of chipping in the process of mounting the stone; if it were left at all thick, the rough edges would be visible by reflection at the lower facets, and would, especially if at all dirty, seriously affect the quality of the stone. The shape of the stone is mainly determined by the ratio of the size of the table to those of the bezels in the crown and of the pavilions in the base, which is another way of saying that it is mainly due to the inclination at which these large facets are cut with regard to the table. If the table were exactly half as wide as the stone and the other proportions were accurate, the angle [1] between it and a bezel would be 45°. It is not far from this (see above); a pavilion makes a slightly smaller angle. As is obvious to the eye, the star facets make a much smaller angle with the table, about 22°. It should be noted that a latitude of some 4° or 5° is possible without seriously affecting the quality of the fire of a stone.

Reasonable accuracy in the disposition of the facets on a brilliant is necessary to ensure that all the light which enters it, principally by

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[1] In accordance with the usual custom the angle between the facets is taken to be that between their normals, or the supplement of the salient angle.

way of the table, should be totally reflected from the facets on which it falls at the base and should emerge with little or no loss through the crown, preferably by way of the inclined facets (stars or bezels) in order to produce the best colour effect (fire). A diamond, if properly cut in brilliant form, should appear quite dark when viewed with the table facet towards the source of light, except for the trifling amount of light escaping through the culet. In the case of any other gemstones and of glass imitations a certain amount of light is refracted out through the base of the stone. This property therefore serves usefully for the discrimination of diamond from its imitations.

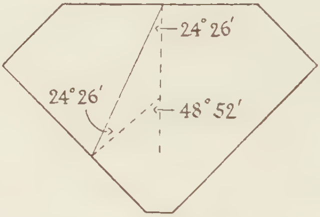

FIG. 91.—Conditions for internal total-reflection in diamond.

In order that no light should escape at the base, it should not be possible for it to fall on the lower facets at angles which are less than 24° 26′, the critical angle of total-reflection for diamond. We see from fig. 91 that the salient angle between these two facets must not be less than 48° 52′, double the critical angle. The pavilion facets, however, make with the table facet an angle which is about 10° less than this value, but we must remember that the bulk of the light which penetrates the table facet impinges upon it nearly at right angles. The corresponding refracted light falls upon the pavilion facet at 39°, which is considerably above the critical value. We can find by calculation that, if the angle between the facets be exactly 39°, the limiting angle of incidence at the table facet to assure that no light is refracted out of the back of the stone is 37° 26′. The amount of light which enters the stone at an angle of incidence greater than this is in practice negligible.

It is not enough to arrange that the beam of light impinges on the lower facets at inclinations greater than the critical angle; it must on reflection be returned to the crown and must meet the exit facet at an inclination within the critical angle, since otherwise it could not emerge. In fig. 92 are shown diagrammatically the paths of rays that entered the table in divers ways. Light which emerges at the table after entering the stone through it undergoes next to no dispersion and is therefore almost entirely colourless, but, if it emerges through the inclined facets, it is then split up into the rainbow effect, known as fire, for which diamond is so famous. If the lower facets were inclined to the table facet at 45° and therefore to each other at a right angle, the incident and reflected rays of light would traverse parallel paths. The alteration by a few degrees of arc tends to divert the reflected beams to the side facets of the crown and thus to accentuate the fire. It might be thought that instead of being faceted the stone might be conically shaped, truncated above and nearly complete below. Apart from the greater difficulty of cutting them in this form the result would be far less pleasing, though perhaps steadier. It is the ever-changing nuance that chiefly attracts the eye; now a brilliant flash of purest white, anon a gleam of cerulean blue, waxing to richest orange and dying in a crimson glow, all intermingled with the manifold glitter from the surface of the stone.

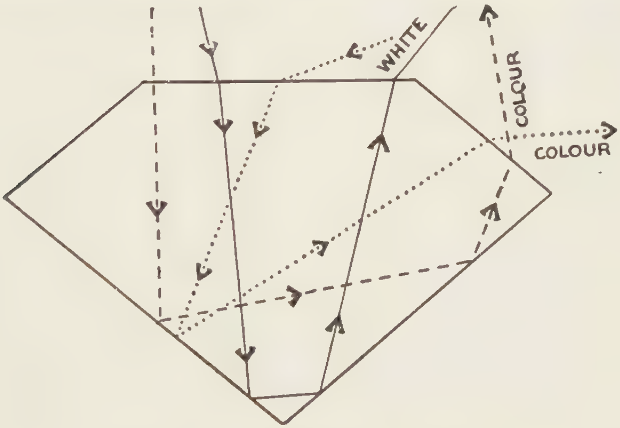

FIG. 92.—Light paths in brilliant.

It should be observed that the relative dimensions given above are those necessary for a full display of fire, but they are by no means always adopted. At the present day it is quite usual to depart from them very considerably, in order to impart to the stone a bigger spread for its weight. The crown seldom has as much as one-third of the total depth of the stone, and often as little as one-sixth; at the same time the table facet is much larger, having about three-quarters of the total width, and the side facets are smaller and inclined to it at smaller angles. The effect, of course, is to give the stone a flatter appearance, and to dissipate much of the fire. This style of cutting is very prevalent to-day.

Absolute cleanliness of any cut gemstone is essential, if its full beauty is to be realized, and this is particularly true of a brilliant-cut diamond. If the back of the stone be clogged with grease and dirt, as so often happens in claw-set rings, light is no longer wholly reflected from the base; much of it escapes, and the life and fire are seriously affected. For that reason rings set with stones should never be worn when the hands are being washed, because on each occasion a soapy film grows thicker on the back of the stones and they become more and more lifeless; equal care should, of course, be taken to remember to restore the rings to the hands. It is surprising how much stones will respond to cleaning. To reach the back of a claw-set stone an orange-stick or even a match-stick with a cotton-wool swab, soaked with benzol, toluol or other grease solvent, should be used; even ordinary water will serve the purpose fairly well.

It is perhaps needless to state that cutters make no careful angular measurements when cutting diamonds, or, indeed, other stones, but judge the position that the facets should assume largely by eye; sometimes, however, the position is checked by means of an angle-gauge. It sometimes therefore happens that the permissible latitude to which we have referred is exceeded, in which event the stone will appear dead and may resist all attempts to vivify it short of the heroic course of recutting it, which is too expensive a treatment in the case of small stones.

The ideal qualities which are required for a brilliant-cut stone are large colour-dispersion (fire), high refractivity and freedom from intrinsic coloration. The only gemstone that can on the whole vie with diamond in these factors is zircon. Although a colourless zircon is very rare in nature, the colour of certain yellowish zircons is readily and permanently driven off by the application of heat. A brilliant-cut 'fired' zircon is, indeed, not readily distinguished by eye, since it is brilliant and well possessed of fire (colour-dispersion). It may, however, be distinguished without difficulty by its double refraction (p. 359) and its lower refractivity, which will cause an appreciable amount of light to escape through the back of the stone; moreover, owing to its inferior hardness a zircon is certain to show scratches on the exposed facets after a few years' wear. The remaining colourless gemstones, such as white sapphire (corundum), topaz and rock-crystal (quartz), are comparatively deficient in fire, besides being low in refractivity.

3 MODIFIED BRILLIANTS

In order to maintain the weight of a stone without serious interference with the optical display, a modified form of brilliant, called the star-cut of Cairo (fig. 93), has been introduced. The table is considerably reduced in size and measures only a quarter of the width of the stone, while the culet, on the other hand, is increased in size and may be nearly as large as the table. The ratio in depth of the crown and the base is maintained at about one to two. The symmetry of the cutting as seen from above or below is hexagonal (sixfold) instead of octagonal (eightfold). The crown consists of the table, six star facets, six templets, and twelve cross facets, making in all twenty-five facets. In the base the cross facets remain, but the pavilions have been replaced by a complex system, and the arrangement consists of the culet, six lozenges, a second series of six lozenges and interspersed between them six small quoins, radiating from this pair of series a triple series of eighteen skill facets, and twelve cross facets, making in all forty-nine facets. The total number of facets on the stone is therefore seventy-four.

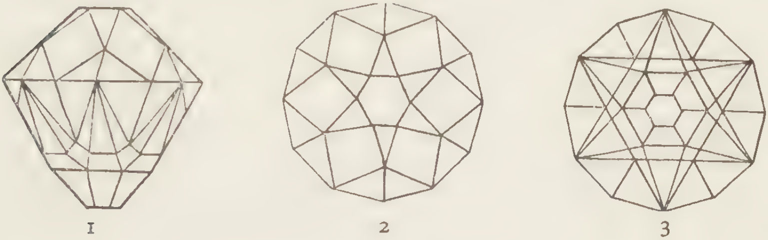

FIG. 93.—Cairo star: (1) side, (2) crown, (3) base.

FIG. 94.—American brilliant: (1) side, (2) crown.

Since much of the attractiveness of a cut diamond is due to the sparkling effect of the reflections from its facets, constantly changing with every movement of the wearer, the American-brilliant style (fig. 94) has been devised, in which the width of the table is reduced only to about one third, instead of one half, of the width of the stone, and the ratio of the height of the crown to that of the pavilion is about two to three instead of one to two. This enables an additional set of eight bezels to be provided, bringing the total number of facets in the crown up to forty-one.

A still more modified form was devised in America at the beginning of this century and was named the Jubilee-cut (fig. 95) in commemoration of the sixtieth anniversary of Queen Victoria's accession in 1897. The table and the culet disappear entirely and are each replaced by eight extended star facets, meeting in a point. In the crown the templets are each replaced by a pair of triangular (skill) facets, and an additional series of quoins is inserted between a pair of cross facets and a pair of star facets. In the base a series of quoins is interspersed between the pavilions. The ratio of the depth of the crown to that of the base is two to three.

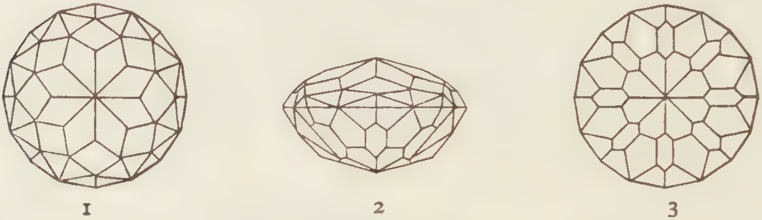

FIG. 95.—Jubilee-cut: (1) crown, (2) side, (3) base.

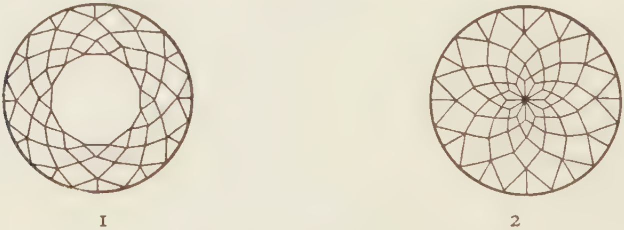

FIG. 96.—Star-cut: (1) crown, (2) base.

In the Jubilee-cut the crown consists of eight star facets, eight quoins, sixteen skill facets and sixteen cross facets, making in all forty-eight facets; and the base, of eight star facets, eight pavilions, eight quoins and sixteen cross facets, making in all forty facets. The total number of facets is therefore eighty-eight.

The beauty of this modified form of the brilliant lies in the multitude of small facets giving a constant flickering of light with the movement of the stone and not so much in the colour effects, which are reduced in intensity owing to the comparative shallowness of the base.

A complicated star-cut brilliant (fig. 96) with numerous small facets in the crown and the base has been introduced for coloured stones.

At the same time other forms have been used with fewer facets. Thus in the English-brilliant (fig. 97) the bezels and half the cross-facets are omitted, leaving besides the table eight star facets and eight cross facets, altogether seventeen facets. On the under side there are eight corresponding cross facets, but only four pavilions, making altogether with the culet thirteen facets. On the whole stone therefore the number of facets is thirty instead of the normal fifty-eight.

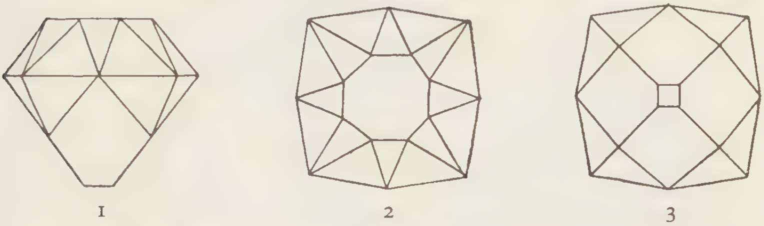

FIG. 97.—English brilliant: (1) side, (2) crown, (3) base.

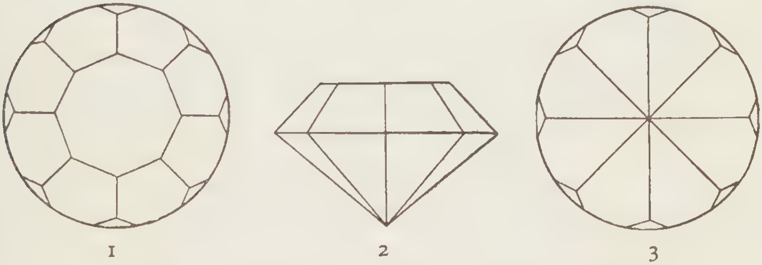

FIG. 98.—Eight-side: (1) crown, (2) side, (3) base.

In addition there are a simple eight-sided form (fig. 98), in which besides the table and the culet there are eight bezels and eight pavilions, and another slightly less simple (fig. 99), in which eight cross facets are added both above and below the girdle.

FIG. 99.—Sixteen-side: (1) crown, (2) side, (3) base.

The commonest distorted shapes are the marquise [1] or navette (fig. 100) and the pendeloque, or drop-form (fig. 101). Apart from the general distortion the arrangement of the facets is normal.

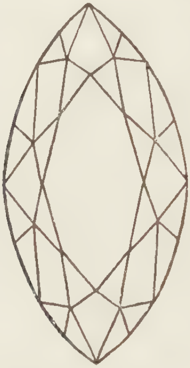

FIG. 100.—Marquise or navette.

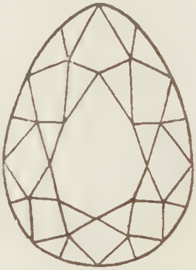

FIG. 101.—Pendeloque, or drop-form.

4 STEP- OR TRAP-CUT STONES

A popular style of cutting, which is much in vogue for coloured stones, is the step- or trap-cut (fig. 102), which consists of a table facet and series of facets, each similarly disposed so that the contour of each runs parallel to that of the table. The general effect resembles a series of steps, and has therefore given rise to the commoner name for this style. The contour may, of course, be varied at will; it is commonly oblong or square, but may be lozenge- or heart-shaped, or have less regular forms.

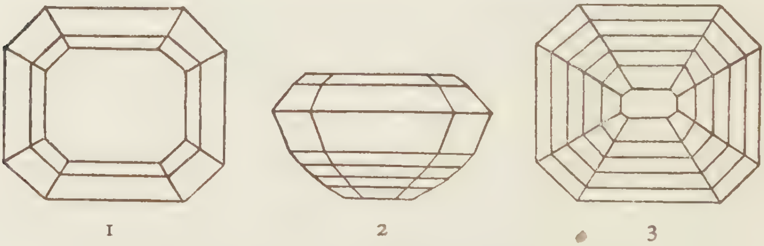

FIG. 102.—Step-cut: (1) crown, (2) side, (3) base.

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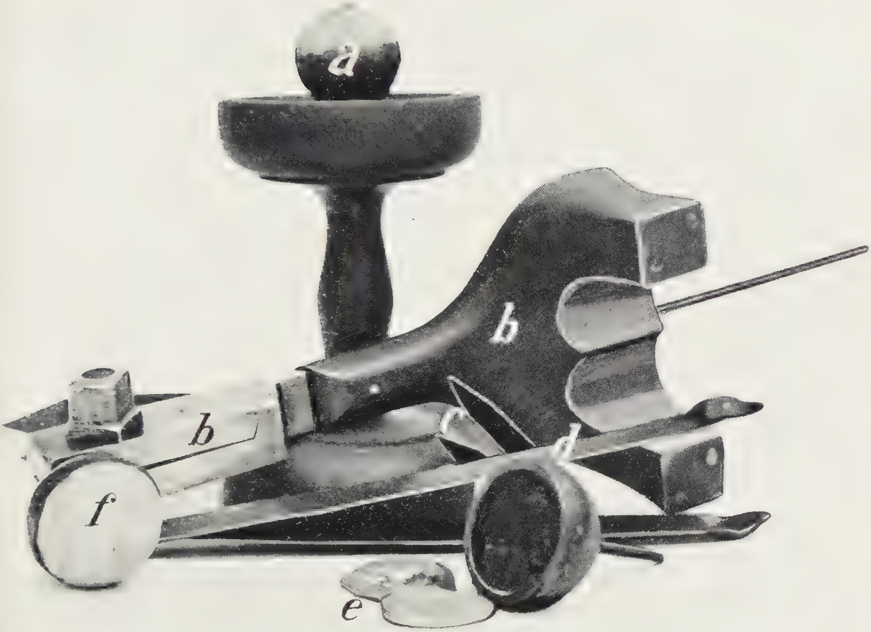
[1] Marquise is the feminine of *marquis*, and literally means marchioness; it has long been used in French for a finger-ring with a cluster of stones, pointed at either end, which covered much of the phalange (bone). Navette, a French word, meaning little boat, comes from the late Latin *naveta*, the diminutive of *navis* (boat): it is also employed for the boat-shaped censers used in churches.



a. Dop on stand. *b*. Arm (from polishing machine) holding dop. *c*. Tongs for handling heated dop. *d*. Tongs for shaping solder. *e*. Solder. *f*. Dop with mounted diamond.

IX. APPLIANCES USED IN DIAMOND POLISHING

a, *b*. Dops, mounted upright. *c*, *d*. Dops, mounted in inclined positions. *p*. Pins preventing rotation of arms.

X. DIAMOND POLISHING

The table is sometimes slightly rounded. Many special names, such as baton, from the French word *bâton* (rod) and baguette, the diminution of the French word *bague* (ring), have been used for various modified step-cuts used on smaller stones.

Since the object of this style of cutting is primarily to display the intrinsic colour of the stone, and not so much to provoke a brilliant play of light from within, no attempt is made to secure total-reflection at the lower facets and a considerable proportion of the light that enters the stone escapes at the base. The stone, when cut, varies in depth according to the depth of its colour. If the tint be dark, the stone is kept shallow, lest light be wholly absorbed within and the stone appear black or opaque; if, on the other hand, the tint be light, the stone is cut deep in order that as much fullness of colour be secured as possible. No great precision in the shape and disposition of the facets is demanded, and, provided therefore that the desired effect be obtained, the stones are usually cut in such a way as to keep the weight as heavy as possible and thus to realize the highest price.

At the present time the so-called emerald-cut has become very popular for diamonds of fine quality, but for this purpose the proportions of the stone must be kept to the limits given for the brilliant form. Thus of the three series of traps above the girdle the upper, middle and lower are inclined to the table facet at angles of about 36°, 43° and 50° respectively, and in the case of the two series below the girdle the corresponding angles for the upper and lower are 40° and 45–50°, though some latitude from these values is allowed. In a square- or oblong-shaped stone there are eight traps above and twelve traps below the girdle, the total number of facets including the table and culet being twenty-two; if the corners be bevelled, the number of traps is doubled, making sixteen above and twenty-four below the girdle and the total number of facets forty-two.

5 MIXED-CUT STONES

At the present day the older step-cut has been much improved by merging it with the brilliant-cut, and thus forming the mixed-cut; the colour effect remains unimpaired, but the general appearance has been enhanced by the increase in the scintillations. The crown has much the same form as in the brilliant, except that the table facet is relatively wider and higher, the ratio to the diameter and to the height being respectively about 60 and 37 per cent instead of 50 and $33\frac{1}{3}$, and the base, though step-cut, possesses much the same proportions as the brilliant. The number of facets may be varied to suit the taste or the requirements, but the facets of the crown and the base always correspond, so that the number of facets forming the girdle is the same above and below (fig. 103).

A pleasing variant of this form is the French-cut, in which the girdle and the table are both square in outline, but the two squares are mutually inclined at half a right angle. The crown is normally brilliant-cut, but the base may be either brilliant- or step-cut.

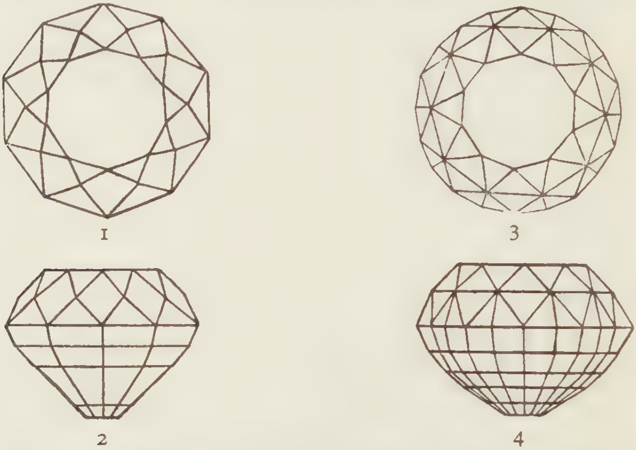


FIG. 103.—Mixed-cut: (1) crown, (2) side; (3) crown, (4) side.

In considering what will be the optical effect resulting from any particular shape of a stone, regard should be paid to the effective colour of the transmitted light. For instance, although ruby and sapphire are varieties of the same mineral species and have therefore the same refractive indices, yet, since the former transmits mainly blue and the latter red light, they have for practical purposes appreciably different optical properties. Lapidaries have, indeed, found from experience that

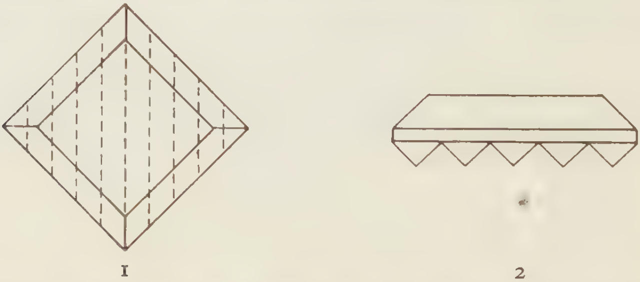


FIG. 104.—Princess cut square stone: (1) upper surface, (2) side.

it is possible to cut the base of rubies sensibly thicker than that of sapphires, with a corresponding advantage in the weight, and yet secure an equally satisfactory result.

6 PRINCESS CUT

In 1961 a completely new cut, originated by Mr Arpad Nagy, was introduced by Diamond Polishing Works Limited. The diamonds are cut into plates 1·50 mm. thick by gang-sawing. These plates are shaped to various standard profiles with a bevelled periphery, polished on the upper surface, and grooved at intervals of 0·90 mm. on the lower (fig. 104). The accuracy of shaping enables the diamond mounter to build up attractively designed jewellery.

B. MACHINERY

The apparatus used in the fashioning of gemstones is simple in character and differs little in principle from the mechanism which was originally used for faceting diamonds. The improvements which have been introduced have been in details and in the use of power; the labour of cutting diamonds has thereby been rendered much easier and the work quickened. Thus, two years were occupied in cutting the Pitt or Regent diamond, whereas in only six months the colossal Cullinan stone was shaped into two large stones and over a hundred smaller ones with a relatively far smaller loss of material.

In the East little change has been made since the days when Tavernier visited India. The lapidaries still use a vertical wheel for grinding and polishing stones, driving it by means of a bow drawn by one hand across the spindle while the other hand applies the stone to the flat side of the wheel. The impossibility of keeping the stone steady in this way, while being worked, explains why native-cut stones seldom have truly plane faces.

Obviously a sharp distinction obtains between diamond and all other gemstones and ornamental stones, since it stands far beyond all the rest in degree of hardness and can be cut only by the aid of its own powder. The process of cutting diamonds therefore differs materially from that in use for other gemstones, however much they may agree in principle, and will be discussed separately. So different, indeed, are the two classes of work that few firms undertake both of them.

i Diamonds

The regular octahedron, to which in fact it is feasible to reduce any untwinned piece of diamond by cleavage, was the original form from which the brilliant style was developed, and the lapidary must still keep before him a mental picture of it when deciding upon the best mode of treating a stone which he has been commissioned to cut.

I CLEAVING

The initial and fundamentally important step is to decide whether the piece is sufficiently well shaped for cutting into whatever may be the desired form, and, if not, how best to split it. It will be remembered that at any point of a diamond there are four different directions of cleavage. It would obviously therefore be disastrous if the stone should split in the wrong direction or even if flaws should develop. The piece is carefully examined in order to determine the directions of cleavage or, what comes to the same thing, the position of the underlying regular octahedron. Even if no crystal faces are developed, the skilled eye can detect these directions by noting the grain on the surface, which is really formed by the intersections with the surface of the cleavage planes which have the smallest inclination with it.

When the position of the cleavage plane required has been definitely ascertained, the diamond is cemented in a holder and a smaller diamond similarly mounted is used to scratch a nick in it in the required direction. A heavy blade is placed in the proper position on the stone and smartly struck; the stone then splits across.

Although the brilliant form of cutting diamond has been developed from the regular octahedron figure, which, if not already the crystal form, could be produced by cleavage, it by no means follows, because diamond can be split to form an octahedron, that such is in practice the initial style in shaping the rough mass. The lapidary's aim is to form the largest possible stone out of the piece entrusted to him, and the stone when finished may bear no relation whatever to the cleavage octahedron. The chief use of the splitting property is to free the rough mass of an awkward and useless excrescence or of flaws. Although the octahedron is one of the common forms in which diamond crystallizes, it is rarely regular in shape, unless small, and oftener than not the most suitable face of the octahedron is selected to serve as the table facet of the resulting brilliant. The rough mass is sometimes described as of a particular point according to the relation of the table to the underlying regular octahedron. The mass is said to be four-point, if the table be cut parallel to a face of the cube, that is across a corner of the octahedron so that the resulting section is square; three-point, if the table be parallel to an octahedron face; and two-point, if the table be parallel to a face of the rhombic dodecahedron and therefore to an edge of the octahedron, while equally inclined to its two faces meeting in that edge. Since the hardness of diamond varies perceptibly with the direction in the crystal, it is important that the lapidary should determine the point of the mass before beginning to work it (p. 177).

2 SAWING

It is only in modern times that the practicability of sawing diamonds was achieved. When the possibility of grinding and polishing diamonds was discovered, it was believed that it should be possible to split them in a similar manner, but no machinery suitable for the purpose could be devised at that date.

The difficulty of sawing diamond is due to the fact that no harder substance is known, and it can be cut only with its own powder, that is with material no harder than itself. The hardness of a diamond crystal varies very appreciably with the direction, and it is practically impossible to saw diamond in a plane parallel to an octahedron face. The best shape for sawing is the regular octahedron, in which case it is sawn in halves along the square section midway between two opposite corners. Each half is of a shape suitable for cutting as a brilliant.

The diamond saw consists of a phosphor–bronze disk, about 3 inches (7·5 cm.) in diameter, which is rotated by power at a speed of between 5000 and 6000 revolutions per minute about a horizontal spindle. In order to reduce the loss of material to a minimum, the disk is made as thin as possible. Its thickness is only about 0·02 to 0·03 millimetre (about a thousandth of an inch), except at the edge, where it is appreciably thicker, 0·06 to 0·07 millimetre; the reason for this sharp gradation in thickness is to prevent the stone, as the sawing proceeds, seizing the disk and wrecking it. In order to prevent bending, the disk is firmly held by thick washers of such diameter that the annular ring exposed is just a little wider than the section to be cut. The stone is gripped on opposite sides by a clamp, which is forked in shape so that the saw can work between its jaws. The diamond powder is mixed with olive oil, and is worked into the edge of the disk by means of a steel rod. The clamp is held above the saw by an arm, so that the cut works through the stone by the effect of gravity, an adjustable stop preventing over-running.

The process once started is simple in operation and proceeds with little attention. One mechanic is sufficient to look after a battery of sawing machines (plate VII).

3 GRINDING

The old method, which is still in use, for roughly fashioning diamonds, is that known as bruting [1] or shaping. Two stones of about the same size are selected and are each firmly embedded with a hard cement in the pit at the end of two wooden holders, so that the parts to be shaped are exposed. The holders are held, one in each hand, and the stones are rubbed hard, the one against the other, until the surfaces of the requisite size are developed on each. During the process the stones are held over a small box, which catches the precious powder for use in sawing or polishing. A fine sieve at the bottom of the box allows the powder to fall through into a tray or drawer placed underneath, but retains anything larger. By means of two stout vertical pins placed on either side of the box the bruter can retain the holders more easily in the desired position and also obtain the purchase required for the pressure. The effort is thrown mainly upon the thumbs, and the continuance of the work day after day has a very disfiguring effect upon the hands despite the thick gloves that are worn to protect them; the skin of the thumbs grows hard and horny, and the first and second fingers become swollen and distorted.

The labour involved in the bruting of diamonds has been greatly relieved by the introduction of machinery. In principle it resembles a lathe and comprises a horizontal shaft, the head of which has an eccentric adjustment. The stone is attached by means of a hard cement (shellac) to the hollow at the head of a dop [2] measuring about 1 to 1½ inches (3 to 4 cm.) in length and ¾ inch (2 cm.) in diameter, the base of which is screwed on to the adjustable head of the shaft. If it be desired to cut a brilliant with circular girdle, the stone is truly centred; if the form is to be a marquise, which consists of two intersecting circular arcs, the stone is placed the appropriate distance from the centre. Another stone is mounted sideways in another dop, which is screwed to the head of a steel rod, about 18 inches (50 cm.) in length. The bruter places the rod under his arm and rests it near the dop against a stout vertical pin fixed to the bench; in this way he can bring great pressure to bear between the two diamonds. The shaft of the machine makes about 100

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[1] This verbal substantive was introduced from the French as the equivalent of brutage (roughing). It is closely allied to the word brute in its now rather rare meaning of rough or unpolished; thus, 'The value of the brute diamond,' Southey, 1804, *Ann. Rev.*, II, 527.

[2] This is an old Dutch word, meaning shell in reference to the shape of the brass cup originally used to carry the solder holding the diamond during polishing.

revolutions a minute. Great care has to be exercised in the course of the operation to prevent the development of excessive heat, not only because the shellac might melt in the dops, but also because pieces might flake off the stones with consequent loss of material.

4 POLISHING

The development of the facets on a diamond and their polishing is effected by means of a horizontal lap, composed of soft iron, which is found to surpass any other metal in retaining the diamond powder used in the operation. It measures about 1 foot (29 cm.) in diameter and $\frac{1}{2}$ inch (1·25 cm.) in thickness, and is rotated at a high speed, about 2000 to 2400 revolutions per minute. The lap does not come out of the operation unscathed, and the surface quickly wears away under the action of the diamonds which are being polished. In order to prolong the life of the lap the diamonds are not placed on it at random for polishing, but in annular rings of increasing radius as each becomes worn, beginning with the innermost ring of about 2 inches (5 cm.) in radius.

The heat developed at the high rate of rotation of the lap by the friction between it and the diamonds which are being worked is far too great for a cement, however hard, to be used to fix the stone to the dop, and a solder or fusible alloy, composed of one part of tin to three parts of lead, has therefore been substituted; as is mentioned below, a mechanical holder with steel claws has been introduced, which has many advantages.

The dop, which contains the solder, usually has an external diameter of $1\frac{1}{2}$ inches (4 cm.), but larger dops are used for large stones. A stout copper stalk is fixed to the bottom of the dop; it is visible on the right of the dop in the picture (plate IX, below *d*), and two pieces of solder are visible lying in front of it (*e*). The dop, containing the solder, is placed in a non-luminous gas-flame, and heated until the solder softens, when it is removed by means of the small tongs (*c*) and placed upright on a stand (*a*). The long tongs (*d*) are used for shaping the solder into a cone, at the apex of which the diamond is placed. The solder is worked well over the stone, so that only the part to be polished is exposed. A diamond is shown in position on a dop (*f*). The top of the stand is saucer-shaped, to catch the stone should it accidentally fall off the dop, and to prevent pieces of solder falling upon the hand. While still hot, the dop, with the stone in position on the solder, is plunged into water in order to cool it. The fact that diamond withstands this drastic treatment is eloquent testimony to its good thermal conductivity; other gemstones would probably split into fragments. Although diamond is composed of carbon, the temperature at which it burns is so high that no fear need be felt of untoward results following its immersion in the gas-flame. The dop is now ready for attachment to an arm (*b*); its stalk is placed in the groove that runs across the split end of the screw, worked by the nut visible in the picture.

Four arms, each carrying a dop, can be used with one polishing lap, and each stands on two square legs on the bench, the remaining support being provided by the diamond on the lap. Pins (plate X, *p*) are fixed in pairs to the bench, to prevent the arms being carried round by the friction; the one near the lap holds the arm not far from the dop, and the other engages the strong metal tongue at the other end of the arm. Although the arm, which is made of iron, is heavy, yet its effective weight alone is insufficient for polishing purposes, and additional lead weights are often laid on the top of it (see the arm at the back, plate X). The copper stalk of the dop is strong, yet flexible, and can be bent so as to place the diamond in the position corresponding to the facet required to be polished; it will be noticed that, whereas the dops *a* and *b* are upright, the other two are inclined. The polishing material is provided by the powder resulting from bruting and in addition by bort, that is diamond useless for cutting, which is crushed up; a little olive oil is added to retain the powder and serve as lubricant. From time to time as a precautionary measure the dops are cooled by immersion in water, because the heat developed by the friction is so great that even the solder would tend to soften. The stone has constantly to be re-set, about six being the maximum even of the tiny triangular facets near the girdle which can be dealt with by varying the inclination of the dop. As the work approaches completion the diamond is frequently inspected, lest the polishing be carried too far for the proper development of the characteristic fire. When the work is done, the stones are boiled in sulphuric acid, to rid them of all traces of oil and dirt.

The task of the polisher has been considerably simplified by the use of a mechanical dop, fitted with steel claws to grip the stone firmly (fig. 105). This form of dop has, besides the convenience in manipulation, the great advantage that the claw-grip is in no way relaxed, however much heat be developed by the friction of the diamond on the lap, for the hotter the stone becomes the more easily it takes a polish. A copper stalk may be attached to the dop at the other end and is connected to the arm in the same manner as in the older pattern. Even so the whole operation remains as rough and ready as before, and it is eloquent testimony to the amazing skill acquired by the diamond-workers that no want of symmetry can readily be detected in a well-cut stone by eye alone, even with the most careful scrutiny.

When the cutter receives the bruted mass he has first to ascertain its point and therefore the direction of the grain (p. 137). If the stone has been sawn, it is usually four-point, the saw-marks running parallel to one of the diagonals of a square formed by the grain (fig. 106), and, failing saw-marks, a four-point mass usually shows rough or slightly touched areas near the girdle, either above or below, which are disposed at the corners (*H*) of an imaginary regular octagon. The three-point mass has generally a 60° triangular grain (fig. 107) on the table surface, or, if the latter be produced by cleavage, it shows no traces of grain, but its cleavage origin can be recognized; moreover, the rough or slightly touched areas near the girdle will be disposed at the corners (*H*) of an imaginary equilateral triangle. In a two-point mass the grain runs in one direction across the table and there may be a distinct ridge, and in this case the corresponding rough or slightly touched areas will appear at the opposite corners of an imaginary square (fig. 108); if the mass has been

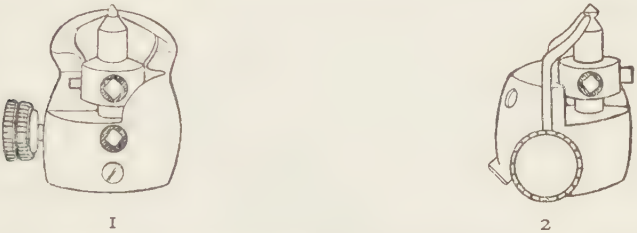

FIG. 105.—Mechanical dop: viewed (1) at right angles to, (2) along, the clamping screw.

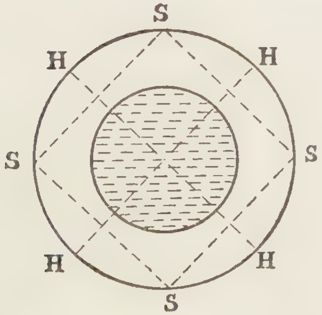

FIG. 106.—Four-point diamond.

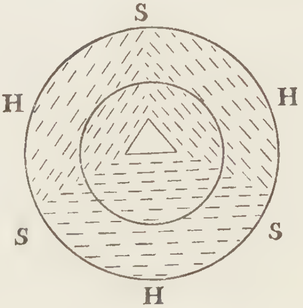

FIG. 107.—Three-point diamond.

sawn, the grain runs across the marks on the table surface. All polishing is done across the grain.

Having identified the character of the mass, the polisher proceeds to grind, preferably on the soft corners (*S*), four templets above and the corresponding four pavilions below to form the cross (fig. 109). Next he superimposes upon the cross, above or below, the companion set of templets or pavilions. On the top of the stone the facets are completed in sets of three, a star and the pair of skill facets nearest to it; similarly, on the bottom each pair of contiguous skill facets are worked together. One templet and one pavilion are left unpolished in order to enable the finisher to detect the direction of the grain. He gives the stone the final touches. In case of need for correcting any errors the bruting is done by hand and not on a machine.

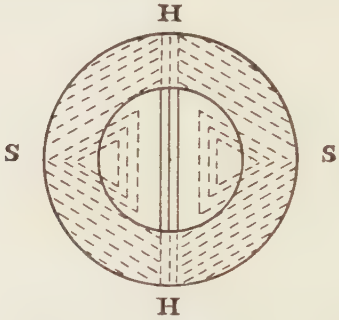

FIG. 108.—Two-point diamond.

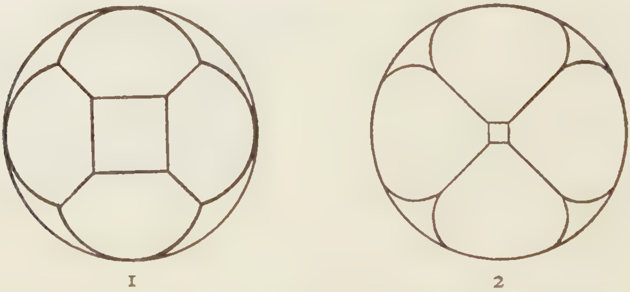

FIG. 109.—Cross, first stage of grinding: (1) crown, (2) base.

ii Other Stones

Because of the relatively inferior hardness of all the other gemstones in comparison with diamond, it is a far easier and quicker operation to cut and polish them than it is diamond. By the use of diamond powder no difficulty is experienced in slitting even the hardest of them, corundum (sapphire, ruby), in any direction at will.

As in the case of diamond, a vertical disk is used for sawing other stones. It may be made of bronze or of soft iron. In diameter it may vary from 4 to 6 inches (10 to 15 cm.), and it is only $\frac{1}{50}$ of an inch (0·5 mm.) in thickness, being made as thin as is feasible in order to reduce the loss of weight to a minimum. The rate of rotation may vary from 1000 to 4000 revolutions per minute, depending upon the hardness of the stone to be sawn; the harder it is, the higher the rate. The sawing element is diamond dust, which is worked into the edge of the disk, and olive oil or paraffin is used as a lubricant. Since comparatively little time is occupied in cutting through a stone, it is commonly held in the hands against the edge of the slitting disk (plate XI). Mechanical holders, however, have now been introduced.

When the stone has been sawn as required, it is firmly fixed to a conveniently shaped holder by means of a cement, which varies in consistency with the hardness of the stone, in such a way that the surface, which has been selected as the place for the table facet, is exposed and set at right angles to the central line of the holder. There is no intermediate operation corresponding to that of bruting in the case of diamond, and all the facets in the upper part of the stone are ground and polished before it is removed from the cement; the lower part is treated in a similar manner.

Owing to the comparatively short time required for grinding or polishing a facet it has been customary to use the hand for pressing the stone on the lap, the inclination of the holder being regulated by inserting its upper, pointed end into one of the holes which are drilled in a vertical spindle placed conveniently near the lap (plate XI); the hole selected is, of course, the one appropriate to the inclination required. The lapidary judges of the position of a facet entirely by eye and touch, but a skilled workman can develop a facet very close to the theoretical position. The task has now been simplified, inasmuch as a machine (plate XII) has been introduced which enables the facets to be quickly and accurately ground and polished. The stone is cemented to the blunt end, *d*, of the holder, *b*, and the pointed end is inserted in the appropriate hole in the wooden piece, *a*, which is adjustable by means of the screw above it. The sides of the octagonal collar, *c*, are pressed successively against the guide, *e*, and the similar facets are thus formed. The machine is, however, not much used except for cheap stones, because it is unnecessarily accurate and thus wasteful of material. It must be remembered that stones are sold by weight, and, provided that the eye be satisfied, no attempt is made to attain the absolute symmetry of shape.

The grinding material for the harder stones is generally carborundum,[1] though diamond powder has been used; for the softer stones emery [2] is preferred. To efface the scratches left by the abrasive material and to impart a high polish to the facets, substances of much less hardness, such as tripoli or rotten-stone, putty-powder (tin oxide), pumice or rouge (haematite), are employed, the lubricant in each instance being water.

The grinding laps are made of copper, gun-metal or lead; and pewter or wooden laps, the latter sometimes faced with cloth or leather, are used for polishing. They measure about 7 to 9 inches (18 to 24 cm.) in diameter and $\frac{3}{4}$ inch (19 mm.) in thickness. The speed is about 1000 revolutions a minute, but varies with the hardness of the stone according to the usual rule, the greater the hardness the higher the speed.

If it were possible to increase the depth of range of vision so as to bring the layers of atoms forming the surface that has been ground within reach of inspection, their comparative level at different parts of the surface would be found to differ widely. The operation of polishing has for its object the removal of the outstanding layers, and is successful in attaining it insofar that the difference in level is reduced to comparatively few atoms and reflections from the facet appear to the eye to be perfect. The nature of this surface is not so simple as this. Investigations which have been carried out by G. I. Finch and other workers, using electron-diffraction methods, have shed considerable light upon the nature of the polished surface of gemstones and the means by which it is produced. In the case of all gemstones, with the exception of diamond, the process of polishing causes a local fusion at the minute projecting points on the nearly plane surface and the consequential spreading of a liquid-like layer over the entire surface. This layer is known as the Beilby layer after its original investigator, Sir G. T. Beilby, whose researches, involving careful observations with the microscope at high magnifications, were carried out at the beginning of the present century.

In relation to the nature of the polish-layer minerals may be divided into the following four groups:

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[1] Silicon carbide, SiC. It is nearly as hard as diamond, but it is not serviceable for the slitting disk as it does not embed itself and is removed at once.

[2] Impure corundum of varying coarseness; the impurities—haematite, etc.—have little abrasive effect.

(*a*) Diamond (and graphite), in which the melting-point appears to be too high for the production of a Beilby layer. In this case the polishing process is merely a matter of very fine abrasion; this was Newton's original conception of the way in which polish of every kind was produced.

(*b*) Minerals, such as quartz and corundum, in which the Beilby layer is amorphous (liquid-like) at the moment of formation, but immediately recrystallizes in orientation similar to that of the substratum.

(*c*) Minerals, such as calcite and kyanite, in which the Beilby layer crystallizes only on surfaces which approximate to important crystal planes, for instance cleavage surfaces and possible crystal faces, or on other surfaces only after heating for some time.

(*d*) Minerals, such as zircon and spinel,[1] in which the Beilby layer remains amorphous on all surfaces.

It should be noted that the Beilby layer must be extremely thin, less in depth than the wave-length of light and perhaps only 40 Å, because otherwise refractometer readings would give refractive indices which were lower than those characterizing the mineral, since a glass has lower refractive indices than a crystal of the same chemical composition.

A curious difference exists in the mode of calculating the cost of cutting diamonds and other stones. In the case of the latter it is based upon the weight of the finished stone, whereas the weight of the rough material determines the cost of cutting a diamond. The reason for the distinction is obvious: the correct proportions of diamonds should be maintained whatever be the loss in weight involved, whereas in other stones the shape is not of such primary importance.

When finished, the stone with others akin to it finds its way to the manufacturing jeweller's establishment, where it is handed to the setter, who mounts it in a ring, necklace, brooch or whatever be the article of jewellery for which it is intended. The metal used for the setting is platinum or one of its group, or gold, and silver finds a place in cheaper jewellery. The stone may be either embedded in the metal or held by claws. The former is by far the safer, but the latter is more elegant, and has, moreover, the advantage of exposing the stone *à jour*, as the

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[1] This property of spinel is important from the point of view of preventing wear in aluminium pistons working in iron or steel cylinders, as in the internal-combustion engine. Aluminium readily oxidizes on the surface, and under friction this film crystallizes as minute corundum spicules, which cut through the oil film and owing to their hardness score the cylinder lining. If, however, the aluminium be alloyed with magnesium, the resultant spinel polish surface remains smooth and amorphous and thus the wear of the cylinder is greatly reduced.

French jewellers say, so that its genuineness is more easily checked; an embedded stone may easily be a doublet or its brilliancy may be due to a piece of foil slipped into the setting. If the stone be set in claws, it is very important that they should be examined periodically, especially if they be of gold; for claws will wear, particularly in rings, and the owner may one day experience the mortification of finding that a valuable stone has dropped out and is lost.

Up to the beginning of the present century jewellery was justly open to the criticism that it was lacking in variety, that little attempt was made to secure harmonious association in either the colour or the lustre of the gemstones used, and that the glitter of the heavy gold mount was frequently far too obtrusive. Times have changed, and so have the taste and workmanship. Elegance of treatment and beauty of line now characterize the best class of jewellery.

C. PRECIOUS METALS USED FOR MOUNTING GEMS

When early man first collected for ornamental use pleasing objects, such as shells, that had attracted his attention, he probably strung them together with fibre; but, when subsequently he picked up brightly coloured or sparkling stones, he looked round for some more durable means of holding the objects, and found it in the native metal that occurred in his district. In parts of the world where gold was found in pieces large enough to be readily picked up it would at once have suggested itself both as intrinsically an ornament and as a mount for other substances. It has an attractive yellow colour, and is unaffected by atmospheric action. It is resistant to fire, and, even though it will succumb at a high temperature, its appearance is unaltered on cooling. For that reason it was known to medieval alchemists as a noble metal. They recognized silver as the companion noble metal, but of a lower quality, because of being soluble in aqua regia. In days gone by silver was in extensive demand both as an ornament and as a mount; but in modern times, when the air of our towns and cities is befouled with coal smoke, it has fallen out of favour because it is so readily darkened by sulphurous fumes.

Both gold and silver were imported into Palestine, and were used, especially the latter, for ornaments for the person or the home, or in connexion with worship. They were also employed as a medium of exchange, first by weight and later as coins.

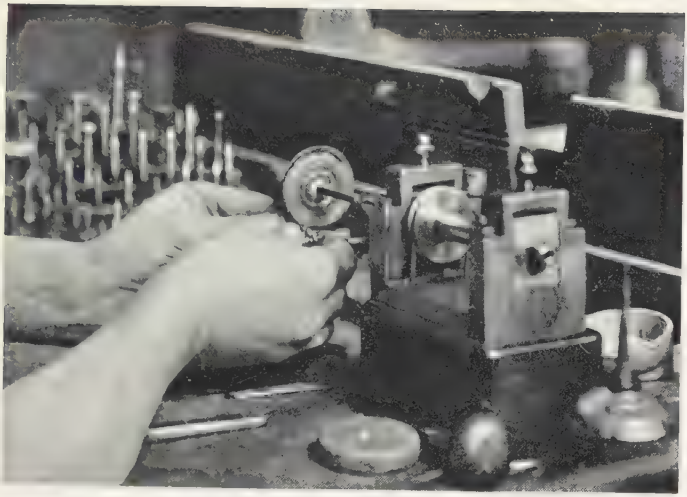
To gold and silver as precious metals have been added in modern times the platinum group of metals, consisting of ruthenium, rhodium, palladium, osmium, iridium and platinum itself. Because of its pleasing and permanent colour platinum is much used in jewellery, particularly for mounting diamonds; it has been displaced to some extent by palladium and the alloy known as 'white gold'. At the present day the metals mainly used for mounting stones are gold (almost invariably alloyed), silver (usually coated with a protective film to prevent tarnishing), palladium and platinum.

XIII

NOMENCLATURE

The names that are still in popular use for the principal species of gemstones may be traced back to very early times, and, since they were applied long before the determinative study of minerals had become a science, their significance has varied at different dates, and it is only within recent years that a serious attempt has been made to reach international agreement upon the names of the stones used in jewellery. No ambiguity or confusion could arise were jewellers to use the names found in mineralogy, but it must be borne in mind that many of them are unknown or at least unfamiliar to those unversed in that science, and that it is not altogether desirable to banish old-established names, even if the task were not almost hopeless. The name, indeed, selected for a newly found gemstone may have a very important bearing upon its fortune. When the love-sick Juliet queried 'What's in a name?' her mind was wandering far from jewels: to them a name is nearly everything. The beautiful red stones that are associated with the diamond in South Africa were almost a drug in the market under their proper title, garnet, but commanded a ready sale under the misnomer 'Cape-ruby'. To many minds there appears to be a subtle satisfaction in the possession of a stone which is assumed to be a sort of ruby that would be destroyed by the knowledge that it really belonged to the cinderella species of gemstones, the despised garnet. For similar reasons it was deemed advisable to offer the lustrous green garnet found some half-century ago in the Ural Mountains as 'olivine', a most unfortunate choice of name, not only because the colour is grass- rather than olive-green, but also because the term is in general use in mineralogy for the species generally known in jewellery as peridot. At the present time the use of such incorrect or misleading names is deprecated by responsible jewellers' associations throughout the world.

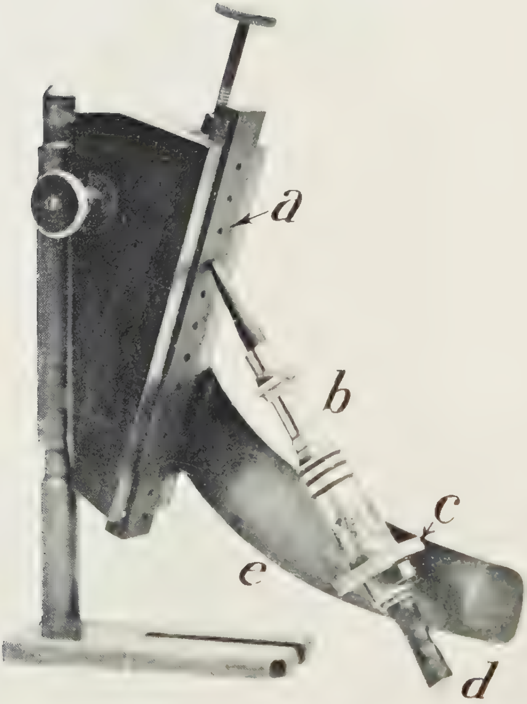
The names commonly used in jewellery were based mainly upon the colour, the most obvious but the least reliable of the physical characters of gemstones. Qualifying terms were introduced to distinguish stones of obviously different hardness. Thus 'oriental' was applied to varieties of



1. Slitting

2. Polishing

XI. CUTTING AND POLISHING GEMSTONES (OTHER THAN DIAMOND)



a. Drilled support for adjustment of holder. *b*. Holder. *c*. Octagonal collar. *d*. Gem mounted on holder. *e*. Fixed guide for collar.

XII. FACETING MACHINE

corundum, the species next to diamond in hardness, not because they came from the East, but because the finest gemstones at one time reached Europe by that road and the hardest coloured stones were consequently accorded that term of distinction. Again, since many fine examples of the true topaz come from Brazil, the qualifying term 'Brazilian' has been used to distinguish that species from the yellow quartz, which has often been called topaz by jewellers.

Nearly all red stones were grouped under the name ruby, with perhaps a qualifying term to separate species differing in tint or hardness, or under names adapted from it, rubellite and rubicelle. Ruby should properly be applied only to the precious red variety of corundum. 'Balas' or 'balais' ruby is the red spinel, such as is associated with the true ruby at the Burma mines and, when cut, is so similar to it in appearance. As has been stated above 'Cape-ruby' is a garnet from South Africa: similar names, such as 'Adelaide-ruby', 'Arizona-ruby', 'Bohemian-ruby' and 'Colorado-ruby', merely mean garnets from the respective areas. Rubellite is the lovely rose-pink tourmaline, fine examples of which have come from California, and rubicelle is an orange-red spinel.

The name sapphire has always meant a blue stone. Originally it appears to have been used for lapis-lazuli or similar mineral, and was transferred to the precious blue variety of corundum upon the discovery of that splendid stone. By early mineralogists the name was used in a wider, almost specific sense for all the varieties of precious transparent corundum, including ruby. Nowadays jewellers use it in the same sense, except that ruby is excluded; thus they speak of white sapphire, yellow sapphire, green sapphire and even pink sapphire. 'Brazilian-sapphire' is really blue tourmaline, a somewhat rare tint for that species, and 'water-sapphire' is a name that has been given to both cordierite (iolite) and topaz.

Yellow stones have tended to be grouped under the name topaz. It properly denotes the hard native aluminium fluosilicate, which when pure is colourless, but enjoys a wide range of tints, thanks to the presence of metallic oxides; jewellers, however, have long been accustomed to using the term both for the yellow variety of this species and for the yellow variety of quartz known as citrine, distinguishing the two by giving the former the prefix 'Brazilian', and even to-day some jewellers cause confusion by speaking of 'Brazilian-topaz' and 'topaz' when they really mean the true topaz and quartz. Possibly as a sop to those who persist in the wrong use of the word topaz, the term topaz-quartz has been proposed for the yellow quartz, but it is almost equally unsatisfactory, because it suggests a mineral species intermediate between topaz and quartz. 'Oriental-topaz', 'king-topaz' and 'Indian-topaz' are yellow corundum, while 'occidental-topaz' is yellow quartz.

The name emerald has always been used for a stone of green colour. It was first applied to chrysocolla, an opaque greenish stone, and later was transferred to the priceless grass-green variety of beryl, for which it is still retained. 'Oriental-emerald' is green corundum. In the eighteenth century 'Brazilian-emerald' was a common term for the green tourmaline then recently introduced into Europe. 'Uralian-emerald' was tentatively suggested for the green garnet from the Ural Mountains, more usually but equally wrongly known as 'olivine'. 'Lithium-emerald', 'copper-emerald', 'Cape-emerald' and 'African-emerald' are respectively hiddenite (green spodumene), dioptase, prehnite and green fluor. It must, however, be noted that at the present day Brazilian emerald and African emerald are correctly used for emerald from Brazil and Africa respectively.

Amethyst is the beautiful violet quartz, but with the prefix 'oriental' it has been applied to violet corundum and even violet spinel, while some jewellers have used the term for the brilliant quartz, with purple and white sectors, from Siberia.

Almandine has come to mean the violet-red garnet, but 'oriental-almandine' and 'almandine-spinel' have been used, though not now, for the violet varieties of corundum and spinel respectively.

Diamond is the name used for the lustrous, extremely hard and, when correctly cut, vividly fiery species which for generations past has ranked as the most popular of gemstones. Unhappily the name has been used also for lustrous colourless stones of other species; 'Cornish-diamond', 'Bristol-diamond' and similar stones are rock-crystal (colourless quartz), 'Matura-diamond' and 'Ceylon-diamond' are colourless zircon and 'Saxony-diamond' is colourless topaz.

Aquamarine is the lovely sea-green variety of beryl; 'oriental-aquamarine' and 'Siam-aquamarine' are greenish corundum and spinel respectively.

Hyacinth or jacinth properly means the reddish-brown zircon, but it has wrongly been used for garnets of similar tint. 'Oriental-hyacinth' is a reddish-brown corundum.

Chrysolite is a word about which there has been some confusion. Properly it is an alternative name for the mineral species, olivine, or peridot as jewellers prefer to call it, but it has often been applied to a totally different species, chrysoberyl. 'Oriental-chrysolite' is the yellowish-green corundum, but it has sometimes been used for chrysoberyl of similar tint. 'Brazilian-chrysolite', 'aquamarine-chrysolite' and 'Saxony-chrysolite' are chrysoberyl, beryl and topaz respectively.

Both chrysoberyl and quartz produce the suitably coloured stones with a streak of light which, when cabochon cut, suggest the eye of a cat. Cat's-eye, without qualification, should be used for the former species only; quartz cat's-eye should be so called.

Jade includes two different mineral species, jadeite and nephrite, but it has been loosely applied to other minerals when presenting a somewhat similar appearance, for instance, serpentine, garnet ('Transvaal-jade') and idocrase ('American-jade' and 'Californian-jade').

Spinel is the hard mineral of that name; 'Arizona-spinel' is a red or a green garnet, and 'Kandy-spinel' is a pale-red garnet from Ceylon.

The gemstones which have been successfully manufactured on a commercial scale are corundum, spinel, emerald, and rutile, and these names, prefixed by the word 'synthetic', may correctly be used for the corresponding artificial product. It is therefore wrong to speak of the reddish-green stones which turn still redder in artificial light as 'synthetic alexandrite', since they correspond to corundum and not to chrysoberyl. Further, the term reconstructed must not be misused; it was introduced for the pieces of artificial corundum which were built up of fused fragments of corundum, and should not be applied to the crystallized products formed from alumina powder.

From what has been said it will be seen that the popular nomenclature for gemstones has the grave disadvantage that it tends to suggest relations between certain species for which there is no foundation and to obscure the essential identity, except from the point of view of colour, of sapphire and ruby, emerald and aquamarine, citrine and amethyst.

The most familiar names used for jewel stones are of great antiquity. They, indeed, came from various sources and did not originate on any definite plan. As, however, an increasing number of minerals were discovered and names were demanded for them, it became the custom in Greek to use the term *λίθος* (stone) for them all, coupled in each instance with a qualifying adjective. Gradually the former was omitted and the adjective acquired the status of a substantive; thus, we find in Greek writers such words as *ἀνθρακίτης* (anthracite), *αίματίτης* (haematite) and *σεληνίτης* (selenite) used in that way. Latin writers, for instance Pliny, assimilated these words, and formed others, as they were required, in the same way by adding the adjectival termination to the term adopted for the particular mineral. The practice passed into the Romance languages, and we find the terminations -ite in French and -ita in Italian, and it was adopted in European languages generally; for instance, -ite in English and -it in German. It will therefore be found that the great majority of mineral names in English end in -ite, and among the more recently discovered gemstones we have accordingly such names as kunzite, benitoite, scapolite and so on. In a few instances, for example almandine, the alternative form -ine, which comes from the adjectival ending *ινος*, Latin *-inus*, is customarily used in this country, though not in the U.S.A.

The Gemmological Association of Great Britain is alive to the importance of giving precision to the various names in use for gemstones in the common interest of jewellers and of the general public. A list of admissible names sanctioned by it is given in an Appendix (p. 543).

XIV

SYNTHETIC STONES

The initial step in the examination of a crystallized substance is to determine its physical and chemical properties, including nowadays its structural arrangement. The converse and by far the harder step is to build it up or synthetically prepare it from its constituent atoms. Unknown to the world at large, research on the synthesis of minerals had long been going on within the walls of laboratories in different parts of the world, and, as the advance in knowledge and technique placed in the hands of experimenters weapons of ever greater efficacy, even when compared with those wielded by nature, their efforts had become increasingly successful and the range of research had been steadily enlarged. So stupendous, however, are the powers of nature that the possibility of reproducing by human agency the treasured stones which are extracted from the earth at the cost of much toil and labour was long discredited by those unacquainted with what had been accomplished. There was consequently some consternation when it was indisputably shown that man's restless efforts to bridle nature had not been in vain, but the position was squarely faced by the jewellery trade with the commendable result that in the principal centres laboratories were established with the object of authenticating gems submitted to them and also of developing fresh techniques as occasion demanded. The identity of a gem is always of at least personal interest, but, so long as a large and even enormous disparity in price obtains between the products of nature and those of the factory, it is of extreme practical importance.

Crystallization may arise in the following different ways:

1. By the separation of the substance from a saturated solution.

In nature the solvent may be not merely water, cold or hot, or water charged with a gas or an acid, but also molten rock; and the temperature or the pressure or both of them may be exceedingly high.

2. By the solidification of the liquefied substance upon cooling.

Ice is a familiar example of this type.

3. By the sublimation of the vapour of the substance, that is, by its

direct passage to the solid state without passing through the liquid state.

This is the least common of the types; the most familiar instance is snow.

4. By the precipitation of the substance from a solution containing it, when set free by chemical action.

Other things being equal, the simpler the composition the greater is the ease with which a substance may be expected to be formed; for, instead of a single substance of complex constitution, two or more different substances may tend to evolve, unless the conditions are nicely and precisely arranged. To take an example: the three molecules—beryllia (BeO), alumina (Al_2O_3) and silica (SiO_2)—if combined in different proportions, would yield different minerals; some experimental work has shown that in certain circumstances silica in the form of tridymite tends to form, and then as the temperature is progressively raised first beryl and finally phenakite is produced. Moreover, the problem is complicated by the fact that a particular substance, for instance silica, will crystallize in different forms according to the conditions of temperature and pressure. The simplest in composition of the gemstones are diamond (crystallized carbon, C), corundum (crystallized alumina, Al_2O_3), spinel (crystallized magnesium-aluminium oxide, $MgAl_2O_4$) and quartz (crystallized silica, SiO_2). Beryl (crystallized beryllium-aluminium silicate, $Be_3Al_2(SiO_3)_6$) has a less simple composition, but owing to the comparative scarcity of natural emerald of high quality its synthesis has attracted considerable attention. The artificial production of these gemstones will now be discussed.

A. SYNTHETIC DIAMOND

Of all gemstones diamond is by far the simplest in composition, being essentially pure crystallized carbon in one of its two manifestations, but its manufacture has been attended by very great experimental difficulties. Carbon cannot be converted by heating into a liquid, because it burns, that is, combines with oxygen from the air, at a temperature well below its melting point. Moreover, the more stable form of crystallized carbon at ordinary temperatures and pressures is graphite.

The earliest research of any importance in the synthesis of diamond was by Hannay,[1] who, in 1880, described a long series of experiments made to achieve the artificial formation of diamonds, which were based

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[1] James Ballantyne Hannay, F.R.S.E. (1855–1931), 'On the artificial formation of diamond,' *Proc. Roy. Soc.*, 1880, vol. 30, pp. 188–9 (Preliminary note) and pp. 450–61.

upon the fact that, when a gas containing carbon and hydrogen was heated under pressure in the presence of lithium, potassium, sodium or magnesium, the hydrogen combined with the metal and the carbon, being thus set free, was deposited in a very hard, scaly form. He supposed that carbon under such conditions might crystallize out as diamond. Undismayed by numerous failures due to the inability of the tubes used to withstand the pressures caused by the heat and exploding or otherwise losing the contained gases, he patiently tried still thicker tubes and other ways of sealing them, and experimented with various ingredients. He finally discovered that lithium gave the only promising results, and, by using 4 milligrams of it, and a mixture of 10 per cent of carefully rectified bone-oil and 90 per cent of paraffin spirit,[1] he obtained a hard, smooth mass which covered the bottom of the tube and adhered to its sides. On grinding this mass, he discovered in it small, transparent pieces, which on examination proved to be diamonds. Some of these small particles were submitted to Story-Maskelyne,[2] then Keeper of Minerals in the British Museum, who, after subjecting them to careful examination, came to the conclusion that they were indeed diamonds. In a letter which appeared in *The Times* on 20 February 1880, he announced Hannay's success in these words: 'There is no doubt whatever that Mr Hannay has succeeded in solving this problem [the production of diamond] and removing from the science of chemistry an opprobrium so long adhering to it; for, whereas the larger part of the great volume recording the triumphs of that science is occupied with the chemistry of carbon, this element has never been crystallized by man till Mr Hannay achieved the triumph which I have the pleasure of recording to-day.' Despite this categorical statement by Story-Maskelyne, Hannay's work attracted little attention at the time, and soon was all but forgotten except by the few who ventured to prospect in the same field of research.

A decade or so later important experiments were made by Moissan,[3] who, being impressed by the discovery of tiny diamonds in the Cañon Diablo meteorite, investigated the solubility of carbon in molten metals (magnesium, aluminium, iron, manganese, chromium, uranium, silver

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[1] In his account Hannay has transposed these percentages, but his meaning is not in doubt, because he has stressed the necessity for using only a small percentage of bone-oil.

[2] Mervyn Herbert Nevil Story-Maskelyne, F.R.S. (1823–1911).

[3] Ferdinand Frederic Henri Moissan (1852–1907). His principal papers are the following: 'Sur la préparation du carbone sous une forte pression,' *Comptes Rendus des Séances de l'Académie des Sciences*, 1893, vol. 116, pp. 218–24; 'Nouvelles expériences sur la reproduction du diamant,' loc. cit., 1894, vol. 118, pp. 320–6.

and platinum) and also in a molten metalloid (silicon). The results, however, were chequered. He met with his greatest success when he placed a carbon crucible, containing pure iron and carbon, in an electric furnace. The carbon dissolved in the molten iron until the latter was saturated and would absorb no more. The molten mass, while still at a white heat, was suddenly cooled by being plunged into a liquid. At first water was used for this purpose, but it was found that better results were obtained by the use of molten lead. When the mass became crusted, it was allowed to cool further in air, the idea being that after a rigid crust had formed continued cooling would cause immense internal pressure, because the liquid expands on solidification. The mass had then to be laboriously attacked by acids until whatever diamonds were contained in it were released from their bondage. Tests showed that the particles scratched a polished surface of ruby, and their specific gravity ranged from 3 to 3·5; moreover, when they were burnt in oxygen, carbon dioxide was produced. The conclusion was therefore reached that the particles were diamond.

Moissan's experiments were successfully repeated by Crookes,[1] who also found minute diamonds in the residues formed in closed steel tubes by the explosion of cordite.

In the Bakerian Lecture for 1918 Parsons [2] gave a full and careful record of the numerous experiments which he had carried out by methods tried by previous workers, but with improved apparatus which permitted of still higher temperatures and pressures, and also of many other experiments by novel methods. Most of the experiments had negative results, and crystallized carbon in the form of diamond was obtained only when iron was present. He repeated Moissan's work and confirmed his results. He also repeated Hannay's experiments with paraffin and dipple-oil, together with the alkali metals, especially potassium, placed in sealed tubes and heated. No diamonds, however, resulted, except when iron was present, not even with much higher pressures than Hannay had been able to use. He pointed out that the latter was mistaken in supposing that a high internal pressure was attained on heating tubes containing water or hydrocarbons, because at a red heat the hydrogen escaped through the metal and the oxygen combined with the steel. Parsons concluded that diamond was formed only when the iron on cooling was solid or at least plastic, because

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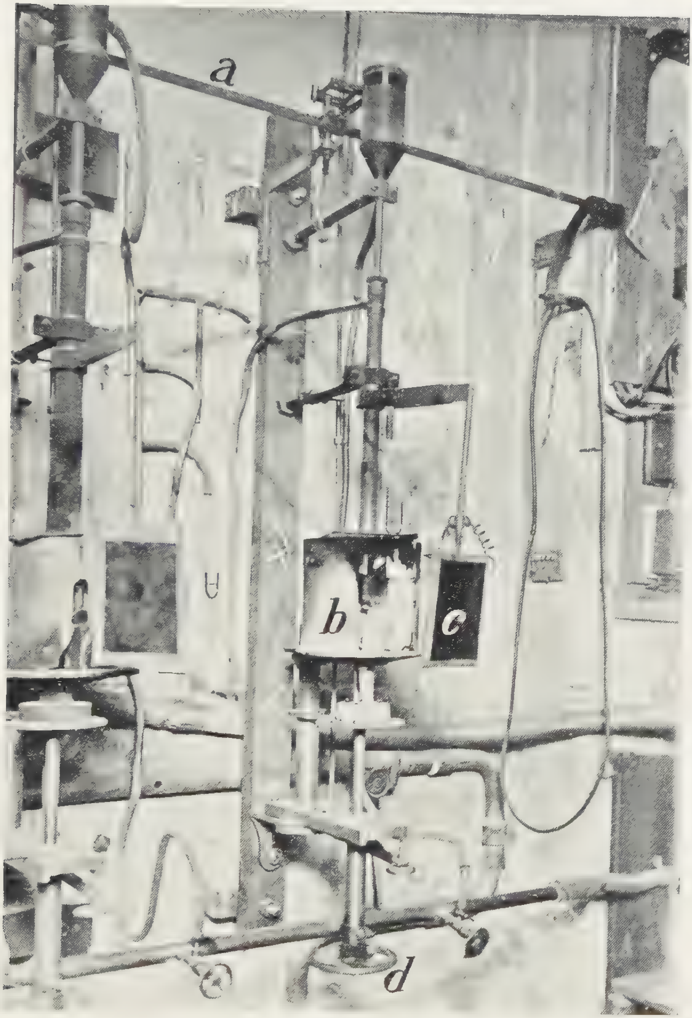
[1] Sir William Crookes, F.R.S. (1832–1919), *Diamonds*, London and New York, 1909.

[2] Hon. Sir Charles Algernon Parsons, O.M., K.C.B., F.R.S. (1823–1911), 'Experiments on the artificial production of diamond,' *Phil. Trans. Roy. Soc.*, A, 1919, vol. 220, pp. 67–107.



a. Cam-shaft. *b*. Fire-clay shield of furnace. *c*. Screen.
d. Adjustment for position of boule.

XIII. VERNEUIL CHALUMEAUX

1. A bank of Verneuil chalumeaux in operation

(Reproduced by courtesy of Salford Electrical Instruments Ltd.)

2. Boules of synthetic corundum (upper row) and spinel (lower row)

(Photo by B. W. Anderson)

molten iron would rapidly destroy the largest diamond yet produced; in fact, a few seconds would suffice.

A few years ago, in connexion with the general investigation of diamond by means of the X-ray probe, the glass slide in the Mineral Department of the British Museum (Natural History), on which were mounted twelve minute particles, stated on the label to have been artificially produced by J. B. Hannay and presented by him in 1880, came under review, and the particles were subjected to X-ray examination.[1] These particles were presumed to be part of the material submitted to Story-Maskelyne in 1880, as stated above. Unhappily, the importance of promptly registering all new accessions was not appreciated at that date, and the slide was not entered in the general register of the Department until 1901, long after Story-Maskelyne's retirement from the Museum. Also the original label was in the handwriting of Thomas Davies, who was on the staff of the Department from 1862 until his death in 1892, and no memorandum by Story-Maskelyne was found with the slide. There remains therefore a shadow of doubt whether these particles were actually among those made by Hannay. On the other hand, the unusual striations noticeable on the cleavage faces agree with Story-Maskelyne's description of Hannay's particles as given in his letter to *The Times*. The investigators therefore came to the conclusion that these particles were some of those that had resulted from Hannay's experiments. One particle, buff-coloured and birefringent, is, however, clearly not diamond; the investigators did not identify it, but thought it to be a ceramic substance. The remaining eleven particles proved to be diamond, and one of them is of the rare type II (p. 260).

It is alleged that during the recent world war the German Government in their desperate need in the production of munitions for industrial diamonds, the supply of which had been cut off by the blockade, made strenuous efforts to manufacture them by the Moissan process, but without appreciable success.

Early in 1955 it was announced by the General Electric Company, Schenectady, New York, that a research team had succeeded in 1954 in crystallizing diamond in the laboratory. Study of the equilibrium relationships between diamond and graphite suggested the possibility of crystallizing diamond under a pressure of 1,500,000 pounds per square inch at temperatures above 2775° C. By further development of the

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[1] F. A. Bannister and K. Lonsdale, 'An X-ray study of diamonds artificially prepared by J. B. Hannay in 1880,' *Mineralogical Magazine*, 1943, vol. XXVI, pp. 315–24.

high-pressure techniques of P. W. Bridgman a pressure vessel was designed which could be operated in this field for periods of time up to many hours. (The pressure was eventually raised as high as 2,500,000 p.s.i.) The work has been directed towards the commercial production of small diamonds for industrial cutting tools and it is stated that four-fifths of the diamonds consumed in industry are of sizes which could be produced in the laboratory. In the years following this achievement the successful recrystallisation of graphite to diamond, in the presence of a metal catalyst, has been reported by a number of other laboratories in the U.S.A., Sweden, U.S.S.R., England, and South Africa. The annual output of synthetic abrasive diamond grit at some of these centres is now of the order of a few million carats, but there seems to be little likelihood at present that the diamond trade will be disrupted by the advent of synthetic material of gem quality.

B. SYNTHETIC CORUNDUM

Ever since jewels were known, rubies and sapphires, of good colour and free from flaws, have ranked high among precious stones, and have accordingly always commanded good prices. Their synthesis has therefore had more than academic interest, and experimenters have prosecuted research in this fascinating field almost continuously since Gaudin[1] succeeded in producing flakes of crystallized corundum. Frémy and Feil,[2] in 1877, were the first to meet with much success, though the thin plates produced were useless for gem purposes. A portion of one of their crucibles, lined with glistening ruby flakes, is exhibited in the Mineral Gallery of the British Museum (Natural History).

i Reconstructed Stones

In 1885, the jewellery market was completely taken by surprise by the appearance of red stones, said to have emanated from Geneva, which had the physical characters of ruby and were therefore accepted as natural stones. It eventually transpired, however, that they were unlike anything that had been seen before, and were the result of the fusion of fragments of natural rubies in the oxyhydrogen flame. The original red tint of the fragments was driven off at the high temperature of the flame, but was revived by the previous addition of a little potassium bichromate before their fusion. Owing to the inequalities of growth, the cracks developed by rapid cooling, the inclusion of air-bubbles, often so

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[1] Marc Antoine Augustin Gaudin (1804–80).

[2] Edmond Frémy (1814–94); Charles Feil (1824–87).

numerous as to cause a cloudy appearance, and, above all, the unnatural shade of colour, these reconstructed stones, as they have since been termed, were far from satisfactory. Nevertheless, they marked such an advance on anything that had been accomplished before, that for some time they were not suspected of being other than natural stones of indifferent quality.

ii Synthetic Stones

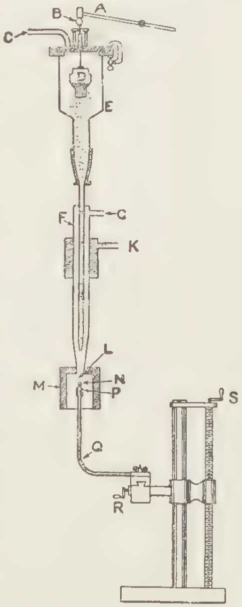

FIG. 110.—Verneuil Chalumeau.

A notable advance in the synthesis of corundum, particularly of ruby, was made in 1904, when Verneuil,[1] who had served his apprenticeship to science under the guidance of Frémy, invented his ingenious chalumeau, an inverted form of blowpipe (fig. 110), which enabled him to overcome the difficulties that had baffled earlier investigators, and to manufacture rubies vying in appearance after cutting with nature's products. The chalumeau—the French word may conveniently be retained for this special form of blowpipe—consisted of two tubes, of which the upper (*E*), wide above, was constricted below, and, passing down the centre of the lower (*F*), terminated just above the orifice of the latter in a fine nozzle. Oxygen was admitted by a tube (*C*), passing through the plate covering the upper end of the tube (*E*). A rod, which passed through a rubber collar in the same plate, supported inside the tube a vessel (*D*) and at the upper end terminated in a small plate, on which was fixed a disk (*B*). The hammer (*A*), when lifted by the action of an electro-magnet and released, fell by gravity and struck the disk. The latter could be turned about a horizontal axis, placed eccentrically, so that the height through which the hammer fell and consequently the force of the blow could be regulated. The rubber collar, which was perfectly gas-tight, held the rod securely, but allowed the shocks to be transmitted to the vessel (*D*), an arrangement of guides maintaining it in an upright position. This vessel, which carried the alumina powder used in the manufacture of the stone, had as its base a cylindrical sieve of fine mesh. The succession of rapid taps of the hammer caused a regular feed of powder

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[1] Auguste Victor Louis Verneuil (1856–1913).

down the tube, the amount of it being regulated by varying the height through which the hammer fell. Hydrogen or coal-gas was admitted by a tube (*G*), passing into the outer tube (*F*), and in the usual way met the oxygen just above the orifice (*L*). To exclude irregular draughts, the flame was surrounded by a screen (*M*), which was provided with a mica window for inspection purposes, and a water-jacket (*K*) protected the upper part of the apparatus from excessive heating.

FIG. 111.—Boules.

The alumina was precipitated from a solution of pure ammonium-alum [1] in distilled water by the addition of pure ammonia, sufficient chrome-alum also being dissolved with the ammonia-alum to furnish about 2½ per cent of chromic oxide in the resulting stone. The powder carefully prepared and purified, was placed, as stated above, in the vessel (*D*), and on reaching the flame at the orifice it melted, and fell as a liquid drop (*N*) upon the pedestal (*P*), which was formed of previously fused alumina. The pedestal was attached by a platinum sleeve to an iron rod (*Q*), which was provided with the necessary screw adjustments (*R*, *S*) for centring and lowering it as the boule [2] grew in size. Great care was exercised to free the powder from any trace of potassium, which, if present, would impart a brownish tinge to the stone. The pressure of the oxygen, low initially both to prevent the pedestal from melting and to keep the area of the boule in contact with it as small as possible, because otherwise flaws tended to start on cooling, was gradually increased until the flame reached the critical temperature, which kept the top of the boule melted, but not boiling. The supply of powder was at the same time carefully proportioned to the pressure. The pedestal was from time to time lowered, and the boule grew in the shape of a pear (now more nearly a cylinder) (fig. 111 and plate XIV), the apex of which was downwards and adhered to the pedestal by a narrow stalk. As soon as the boule reached the size required or the maximum possible with the flame used, the gases were sharply and simultaneously cut off. After ten minutes or so the boule was lowered from the chamber (*M*) by the screw (*S*), or alternatively the chamber was opened, and, when quite cold, the boule was removed from the pedestal.

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[1] $(NH_4)_2SO_4 . Al_2(SO_4)_3 . 24H_2O$.

[2] Boule, the French word meaning ball, is for convenience and clarity used for the drop, originally pear-shaped but now cylindrical, produced by the Verneuil process.

Very few changes have been made in the method, as adapted to commercial use. An attempt to replace the costly hydrogen by coal-gas failed owing to the difficulty of adequate purification. The hammer is often operated by a cam instead of an electro-magnet, while, as may be seen from the photograph (plate XIII), a number of chalumeaux are placed in line so that their cams are worked by the same shaft (*a*). The fire-clay screen (*b*) surrounding the flame is for convenience of removal divided into halves longitudinally, and a small window is left in front for viewing the boule during growth, a red-glass screen (*c*) being provided to protect the eyes from the intense glare. Half the fire-clay screen of the chalumeau in the centre of the illustration has been removed to show the arrangement of the interior. The centring and the raising and lowering apparatus (*d*) have been modified. The process is so simple that one attendant can look after a dozen or so of these machines (plate XIV), and it takes only one hour to grow a boule large enough to provide, when cut, a 10-carat stone.

A simple modification was at a later date introduced into the apparatus with the view of obviating the blemishes that inevitably betray the origin of stones cut from these boules. The pedestal on which the boule was formed was made to rotate, the result being to dislodge the air-bubbles that previously were always found. The absence of such bubbles made the certain identification of these stones less easy, though the curved banding resulting from the slight inequality in the coloration of different layers of the boule during growth was usually detectable. In spite of this improvement, however, rotation has not been generally adopted.

For gem purposes boules are now grown nearly cylindrical in shape. Usually they are divided longitudinally through the central axis into halves, which in shape, if not in crystal orientation, are admirably suited to the purposes of cutting; as a rule the boules split during cooling into the desired direction of their own accord, owing possibly to the development of a plane of parting through twinning. During recent years and particularly during the war recourse has been had to synthetic corundum as the most reliable material for the bearings of measuring and time-keeping apparatus. Boules of the ordinary shape may be used for this purpose, but the waste of material involved is heavy, and to overcome this difficulty a different process of manufacture has been devised; it is described below (p. 201).

Each boule is a single crystalline individual, and not, as perhaps might have been anticipated, an alumina glass or an irregular aggregation of crystalline fragments. The cylindrically shaped side of the boule is usually bright and smooth with no indication of crystal faces, but the dome, or rounded end, may be rough, because of the development of a fine network of lines, mutually crossing at angles of 60°. Goniometrical examination has shown that this network is a reticular formation of minute faces corresponding to the fundamental rhombohedron of corundum, $r\ \{10\bar{1}1\}$.[1] At the broken end, where the boule was severed from the pedestal, a good plane of parting, parallel to the basal face and therefore at right angles to the crystallographic axis, may be visible. If the boule has been allowed to cool evenly, the crystallographic axis will be found to coincide fairly closely with the axis of the boule; but, as careful precautions are not necessarily taken in commercial practice, the crystallographic axis may be inclined to the axis of the core and in extreme cases may even be at right angles to it, although it always lies in the plane in which the boule has split. Since therefore the boules have the internal, though not the normal external, development characteristic of corundum, the stones cut from them have the same physical properties—hardness, specific gravity, refractivity, double refraction, dichroism and so forth—appertaining to the natural species. Consequently they respond to precisely the same tests with the refractometer and the dichroscope as the natural stones, and, if it were not for certain characteristic imperfections, it would be impossible to distinguish with confidence between the stones formed in nature's vast workshop and those grown by human agency within the confines of a factory.

Synthetic stones are practically never free from air-bubbles (plate V, fig. 2), which are easily visible with an ordinary lens of low power, though, if minute, they resemble specks of dust. They are spherical in shape and their apparently circular outline is unmistakable and sure evidence of the stone's origin. A natural stone may have inclusions (plate IV, figs. 1, 2, 3), flaws or cavities, but they are never circular in contour. There is another diagnostic feature which clearly distinguishes the synthetic stones, especially when coloured. Clear and limpid as they seem, they are not quite uniform in structure. If the interior of the stones be examined—it is best for this purpose to use a microscope, illuminate the stones strongly, and immerse them in oil to facilitate the passage of light—curved striae or lines of growth will usually be clearly visible. These striae are sections of successive shells of the original boule, since the colouring matter has varied slightly but perceptibly during its growth, resulting from the intermittent tapping of the hammer on the

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[1] G. F. Herbert Smith, 'Note on synthetical corundum and spinel,' *Mineralogical Magazine*, 1908, vol. XV, pp. 153–5.

powder cage. In a natural stone, on the other hand, although bands of different colours or varying shades are not uncommon, the markings due to them are invariably straight, corresponding as they do to the plane faces of the original crystal. If then the stone, when studied under a microscope, appears to be full of curved striae, its synthetic origin is beyond doubt.

The success which attended the manufacture of ruby encouraged efforts to produce other varieties of corundum. The reduction in the percentage amount of chromic oxide lightened the colour, and pink stones were evolved which in their tint were not unlike the fired topazes, the original yellow colour of which has been altered by the application of heat. The synthetic stones were therefore at first called 'scientific topaz'; of course, quite wrongly, since topaz is an entirely different gemstone.

The initial attempts to achieve the exquisite blue tint of the true sapphire met with an unexpected difficulty. The colouring material used, cobalt oxide, refused to diffuse evenly through the boule, and instead concentrated in isolated splotches, and it was found necessary to add a considerable amount of magnesia as a flux before a uniform distribution of colour could be secured. It was then discovered that despite the colour the stones had the physical properties not of sapphire, but of the species closely allied to it, spinel (magnesium-aluminium oxide). Goniometrical examination of the reticulated formation of the rounded end of the boule, where the lines of the network met in this instance at right angles, showed it to correspond to the faces of the octahedron, *o* {111}, and, to a minor degree, of the cube, *a* {100}, also.[1] The crystal form of these boules is therefore the same as that of spinel, namely cubic. By an unsurpassable effort of nomenclature these blue stones were at first given the extraordinary name of 'Hope sapphire', from fanciful analogy with the famous blue diamond, which once was the pride of the Hope collection (p. 234). A blue spinel is occasionally found in nature, but its tint is different.

At the close of 1909 Verneuil succeeded in producing blue corundum by employing as tinctorial agents titanium oxide (0·5 per cent) and magnetic iron oxide (1·5 per cent), but these stones had not quite the tint of sapphire. Stones of better colour were obtained in later experiments by omitting the iron oxide. At the present time some iron is incorporated in the mixture, but it apparently volatilizes during the growth of the boule, no trace of iron being found in the absorption spectrum (p. 112). Sapphire presents greater difficulty than ruby,

[1] G. F. Herbert Smith loc. cit.

because care has to be exercised in regulating the temperature of the flame and the position of the boule in it; otherwise the colour tends to become violet.

Experiments have been made with many colouring agents, with the result that synthetic stones of corundum have been produced in a large variety of different shades. If no colouring matter at all be added and the alum be free from potash, which imparts a brownish tinge, colourless stones are formed. They correspond to white sapphire in nature, and have been called 'walderite'. An attempt was made to use the term 'scientific brilliant', which is obviously wrong and misleading, for these stones have nothing to do with the true brilliant, which is the term used for diamond cut in a particular form (p. 158).

The use of nickel oxide as colouring agent has resulted in yellow stones of almost every imaginable shade. A peculiar reddish-yellow variety has received the name, padparadschah, from the Sinhalese word *padmaragaya* (lotus-colour).

Stones which have been coloured by vanadium oxide are of much interest, for their colour is of a balanced character, so that they appear reddish-green in daylight but still redder in artificial light. In nature this phenomenon is known only in the variety of chrysoberyl called alexandrite (p. 361). For that reason these stones were at first wrongly called 'scientific alexandrite', a misnomer that has long been dropped. Synthetic corundum of various other shades of green, approaching those typical of emerald and tourmaline, is produced by the addition of cobalt, magnesium, zinc or other metals to the vanadium; and a pistachio-green results from the use of nickel, iron and titanium. The name amaryl [1] has been given to the clear green kind. By the agency of chromium, iron and titanium violet stones are obtained.

No difficulty is experienced in effecting abrupt changes in different shells of the boules, and the stones cut from them are reminiscent of the variegated tourmalines familiar in nature.

Besides its use in jewellery, synthetic corundum has increasingly found its way into industry, and is now in universal demand for such purposes as the bearings of the moving parts of watches and other instruments of precision for which cheap, durable and, above all, reliable material is required. While the form of the cylindrical half-boules is well adapted for cutting into the shape ordinarily selected for a jewel stone, it is very wasteful if the material is required for bearings, losses amounting to as much as 98 per cent. It has, however, been found that by

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[1] The name was apparently suggested by the colour of the leaves of the Belladonna lily (*Amaryllis Belladonna*).

reversal of the blow-pipe arrangement it is possible to grow slender rods; slices cut from them by a diamond-charged disk need no shaping and have only to be drilled and polished, with great saving in material, the wastage being only 2 per cent. The raw material, which is an extremely fine powder, its particles being of the order 0·0001 mm. in diameter, is vibrated downwards into the stream of gases, which must be absolutely pure and dry, and wafted into the combustion chamber of an upward-pointing blowpipe. The furnace, when in operation, is singularly unimpressive, being quite noiseless and radiating next to no heat. The optical orientation of the rod may very simply be determined by using as its support a stub of previously synthesized corundum which has the desired orientation, since the new material will crystallize in complete harmony with the old.

Once the rod starts to grow its diameter and rate of growth are regulated by the speed at which its support is raised. This is effected mechanically by means of a small electric motor operating reduction-gear. By an ingenious arrangement an image of the glowing rod is thrown on to a screen, on which guide lines are drawn, and the rate of growth is adjusted so that the image fills the space thus outlined. Rods of about 0·09 inch (2·3 mm.) in diameter are grown at the rate of about 1 inch (25 mm.) per hour. A length of 10 to 12 inches (25–30 cm.) is common, and rods as long as 24 inches (60 cm.) are known. If the rods, when formed, be passed through the flame, their cylindrical sides assume a beautifully clear and lustrous appearance. It is possible to bend the rods, when hot, with pliers without breaking them. Rods bent like the handles of walking-sticks are used in the manufacture of artificial silk. Experience has shown that the rods are brittle, if either too thick or containing too much chromium oxide. It might well be asked why coloured material is required, if it is to be used merely for bearings; the answer is that an indiscriminate public accustomed to see bits of red jewels used as bearings in their watches are suspicious if they see the bearings to be uncoloured.

It has been found by experience that, if the rods are to form suitable material for bearings, their optic axes must nearly coincide with their length. Those with optic axes almost at right angles to their length proved to be useless until they had been carefully annealed at a temperature above 1500° C. It has been found desirable in practice to anneal all the rods after they have been formed. In 1956 ruby was successfully grown from solution by C. F. Chatham, apparently using a process similar to that developed for emerald (p. 205). Corundum has also been crystallized by the fluxed-melt technique from a solvent with high melting-point.

Both star-sapphires and star-rubies of excellent quality have been synthesized in the United States of America and Germany, the asterism being produced by fine rutile needles (p. 116).

C. SYNTHETIC SPINEL

Experiments in the synthesis of spinel were continued after the production of blue stones, coloured by cobalt, to which reference was made in the preceding section. It was found by Paris, a pupil of Verneuil's, that by the substitution of lime for magnesia blue stones were formed which did not suffer from the disadvantage attending the earlier ones, namely that they turned purple in artificial light.

From a powder composed of pure magnesia and alumina colourless boules have been formed, which yield beautiful limpid stones on cutting. So beautiful are they that on their first appearance a foolish attempt was made to pass them off as a kind of artificial diamond, as was stated above (p. 200). By the addition of chromic oxide in different proportions, various shades of red and pink have been obtained, just as in the case of corundum, though they are seldom to be met; if, however, the temperature of the flame be raised, the result is a green boule. In fact, very much the same range of colour has been attained as in synthetic corundum, including the balanced shade of green which changes to a reddish tint in artificial light. The chief distinction of synthetic spinel is in the blue: all shades of this colour, including the popular zircon-blue, have been produced, and it is these which have been most in demand, imitating, as they do, aquamarine and even sapphire, as well as zircon. All these cobalt-coloured spinels are, however, easily recognized by their red tint, when viewed through the Chelsea filter (p. 94).

The remarkable and unexpected feature of the synthesis of spinel is the discovery that alumina can combine with magnesia in considerably greater proportion than the equal molecular ratio without any drastic alteration in the crystal structure. Indeed, synthetic spinels are said to vary from the normal composition, $MgO . Al_2O_3$, to $MgO . 5Al_2O_3$,[1] although the stones that come into the market conform more nearly to the composition $MgO . 2Al_2O_3$. These last have normally a specific gravity of 3·63, the range being from 3·62 to 3·65, and a refractive index of 1·727, the range being from 1·725 to 1·730. These values are perceptibly higher than for the normal natural stones.

A satisfactory red spinel has only more recently been produced, and it is interesting that these synthetic stones do have an approximately equimolecular composition. Moreover, their specific gravity of 3·579 to

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[1] F. Rinne, *Neues Jahrb. Min.*, Abt. A., 1928, vol. 58, pp. 43–108.

3·598 and refractive index of 1·719 to 1·720 are within the range of figures for natural stones (p. 324). Their colour, however, is more like that of a ruby than of a natural spinel and they can be distinguished by their characteristic fluorescence.

The synthetic stones almost invariably show optical anomalies, such as slight double refraction between crossed nicols and even a suggestion of a negative uniaxial figure in convergent light, and, moreover, show distinct signs of variation of refractive index with direction, sometimes amounting to as much as 0·002.

D. SYNTHETIC EMERALD

So attractive and coveted is the grass-green variety of beryl known as emerald, and so high are the prices commanded by stones of the best quality, that its successful synthesis had more than mere academic interest. Even the modest success that had attended the recrystallization of rubies from fragments of natural stones was encouraging enough to lead to similar experiments with powdered beryls, the colour driven off by the heat of the oxyhydrogen being restored by the previous addition of a small percentage of chromic oxide. The experiments, however, were a failure, the result of the fusion being in every instance not a crystal but a glass; it was therefore a deplorable mistake to name such products 'scientific emerald', since they were not emerald or especially scientific. They differ from the true emerald in several respects: the colour, though still a green, is a leaf and not a true emerald shade, and the physical properties [1]—refractive index, 1·508 to 1·527, and specific gravity, 2·417 to 2·489—are lower than for the crystals. The production of beryl glass by fusion of fragments of beryl in the oxyhydrogen flame is not a novelty, and has, indeed, been known since the beginning of last century,[2] but did not attract the attention of the jewellery world before the possibility of producing synthetic stones was realized.

The first successful experiments in the synthesis of emerald appear to have been by Hautefeuille and Perrey.[3] In the course of lengthy and elaborate experiments in the production of various beryllium silicates they succeeded in obtaining tiny crystals of emerald. The best results

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[1] B. W. Anderson and C. J. Payne obtained the following values: stone coloured by chromium, 6·62 carats, green, 1·517, 2·493; stone coloured by cobalt, 6·47 carats, blue, 1·517, 2·445. The hardness slightly exceeds that of quartz, 7.

[2] Clarke, *Schweigger's Journal*, 1816, vol. 18, p. 237.

[3] Paul Gabriel Hautefeuille (1836–1902) and Alexis Perrey (1808–82), 'Sur les combinations silicitées de la glucine,' *Annales de chimie et de physique*, 1890, ser. 6, vol. 20, pp. 447–80.

were yielded by placing a mixture of beryllia, silica and alumina, in the correct proportions for beryl, under a covering of lithium dimolybdate in a platinum crucible, which was inserted into an autoclave. The temperature, after being gently raised to a dull heat and maintained at that level for twenty-four hours, was raised still higher to nearly 800°, at which point it was maintained for fifteen days. It was found to be important not to allow the temperature to rise above 800°, because instead of beryl the beryllium silicate phenakite, Be_2SiO_4, was formed. In the initial phase a lithium substance crystallized out in octahedra, then with increase of temperature the octahedra became replaced by prisms of beryl, and finally, when the octahedra had disappeared, the larger prisms tended to grow at the expense of the smaller ones. At the close of the experiment the fused mass, when cooled, was powdered, and the crystals of beryl released by digestion in dilute hydrochloric acid. Crystals, which were as devoid of inclusions as possible, were found to have 2·67 as the value of the specific gravity, and their composition was in close agreement with the formula for beryl. At a temperature of 750° the crystals were short, tabular, hexagonal prisms, and near 800° they became more elongated, the length being one and a half times the diameter. The addition of chromic oxide to the mixture imparted to the crystals a green tint which was as intense as in the finest natural emeralds; if the addition was 0·001 of the mixture, the oxide was wholly taken up by the crystals, but, if the addition was as much as 0·003, much of the oxide remained in the gangue. The crystals were almost perfect in form, though far too small for gem purposes.

By a process which has only recently been divulged, and is similar in principle to that just described, the German combine I.G. Farbenindustrie manufactured synthetic emerald and placed it on the market a few years before the recent world war under the trade name 'igmerald'. This material is formed in druses of crystals, as beautifully tinted as the finest natural emeralds, which may reach a length of half an inch (1·27 cm.) and be large enough in size to provide, when cut, stones of at least a carat in weight. The crystals have the shape of an hexagonal prism with the forms a $\{10\bar{1}0\}$ and m $\{11\bar{2}0\}$, terminated by the basal face c $\{0001\}$; occasionally small faces of the pyramids p $\{10\bar{1}1\}$ and s $\{11\bar{2}1\}$ are present. Igmerald has therefore the general characters of beryl, and may be described as synthetic emerald. There are, however, slight differences in the internal texture and in the physical constants which enable igmerald to be distinguished from the natural stones.

Substance	Specific Gravity	Refractive Indices		Double Refraction
		Extraordinary	Ordinary	
Synthetic Emerald	2·65	1·561	1·564	0·003
Natural Emerald—				
Brazil	2·67–2·70	1·566–1·568	1·571–1·573	0·005
Colombia and Siberia	2·70–2·71	1·565–1·574	1·570–1·580	0·006
Transvaal	2·72–2·77	1·580–1·586	1·587–1·593	0·007
Aquamarine and yellow Beryl	2·68–2·80	1·570–1·575	1·580–1·586	0·005–0·006
Morganite	2·78–2·90	1·580–1·588	1·588–1·599	0·008–0·011

In the early crop of material the dichroism—yellowish-green to dark bluish-green—was strong, but it is weak in later crops, though the tints remain the same. Anomalous double refraction, no doubt due to the internal strain arising from too rapid cooling, is at present characteristic, but may be expected to be less noticeable if transition to normal temperatures be effected more gradually. Igmerald displays distinctly brighter fluorescence when subjected to the ultra-violet rays than does natural emerald.

At about the period of the German experiments work was begun also by C. F. Chatham in his research laboratories at San Francisco. The first Chatham synthetic emerald of one carat size was grown in 1935, and since 1940 a steadily increasing commercial output has been achieved. A crystal of good quality weighing 1014 carats has been exhibited at the Smithsonian Institute. The process is apparently a hydrothermal one, involving slow growth on a seed-crystal.

When the internal texture of early synthetic emeralds is examined by means of a low-power microscope or a strong lens, characteristic wisp-like formations (plate XV) of numerous minute liquid inclusions, each containing a gas bubble, which traverse the stones in broad, slightly curved lines, are readily discernible; this phenomenon is quite unlike that of a flawed emerald. In later crops, however, this blemish is absent or at least not so evident, and it cannot therefore be relied upon as a diagnostic feature. The first step in the identification of a doubtful stone should be to place it in a liquid in which quartz just floats, because synthetic emerald will float or at least remain in suspense, whereas natural emerald of similar appearance will sink. Careful measurement of the refractive indices should then be made in sodium light; synthetic emerald has distinctly lower values, especially as regards double refraction. The newest substitute for emerald, termed Emerita, has a thin layer of synthetic emerald grown on a faceted beryl.

E. SYNTHETIC QUARTZ

The synthesis of quartz presents little difficulty, and has long been a laboratory achievement, but the commercial value of even its most attractive variety, amethyst, is not sufficient to justify attempts at the production of gem material; moreover, an ample supply for ordinary jewellery requirements is available from natural sources. It is unlikely therefore that synthetic stones will be encountered in jewellery. Quartz is, however, synthetically prepared for another purpose: as is pointed out below (p. 373), the piezo-electric property of quartz is being much used in broadcasting and timekeeping, but apparently suitable natural crystals are often found to be useless for the purpose because of the latent twinning, which is difficult to detect. It is consequently becoming increasingly necessary for crystals to meet the requirements to be grown artificially.

Quartz is the stable form of crystallized silica at temperatures up to 870°, at which point with considerable increase in volume it passes into tridymite, which in its turn at 1470° passes into cristobalite. It may thus be formed at comparatively modest temperatures. For instance, Hautefeuille produced it by the action of hydrofluosilicic acid, H_2SiF_6, on gelatinous silica in a hermetically sealed platinum tube at 200°.

F. SYNTHETIC RUTILE

Recently the synthesis of rutile (p. 412), a form of titanium oxide, has been successfully achieved in the United States of America. Since the synthetic product is free from the iron which by its almost invariable presence darkens the native mineral, its colours are much lighter, usually clear yellow, though occasionally blue, red or brown. The refractive index for the ordinary ray (in sodium light) is 2·62, for the extraordinary ray 2·90; the dispersion *B–G* is 0·28. These exceptionally high values give a fire exceeding that of the diamond, and a faceted synthetic rutile is an astonishing object. Apart from its characteristic clarity the synthetic material bears the usual evidence of its origin in the form of included bubbles. The very strong double refraction distinguishes it from the synthetic strontium titanate described in the next paragraph.

G. STRONTIUM TITANATE

Attention has recently been drawn towards this substance as a possible artificial gem material. The chemical composition is $SrTiO_3$, which does not correspond to that of any natural mineral, though the substance belongs to the same group structurally and crystallographically as the mineral Perovskite, $CaTiO_3$. The structure is cubic and therefore isotropic. The refractive index for sodium light is 2·410, dispersion *B–G* is 0·19 (about four times that of diamond), and the material is almost colourless. The specific gravity is about 5·1; the hardness, however, is only 6. It was at first proposed to call this material 'Starilian'; it is now known as 'Fabulite'.

H. GENERAL

The general conclusion reached is that, while to prophesy is proverbially dangerous and there is no foretelling what further advances may be made in the artificial production of gemstones, there will always be some divergence between them and the corresponding natural substance, which, though possibly not very pronounced, will to the expert eye inevitably distinguish the synthetic origin. The gemstones which at present need careful scrutiny are corundum and spinel in all their varieties and emerald.

At the time when the reconstructed ruby was a novelty and not too readily detected it commanded as much as £6 a carat, but, as soon as it was known that it could easily be discriminated from the natural stone, a collapse followed and the price fell abruptly to 30*s*. and then to 5*s*. and even 1*s*. a carat; the price of sapphires, when these were first synthesized (a *reconstructed* sapphire was never marketed), ran slightly higher—from 2*s*. to 7*s*. a carat. At first the price of the corresponding natural stones fell, but, as soon as it was realized that the synthetic material could always be recognized, the prices rose to their former level. The extreme disparity between the prices of the natural and the synthetic stones renders the fraudulent substitution of the latter for the former a great temptation, and it behoves purchasers to beware where and from whom they buy, and to be suspicious of apparently remarkable bargains, especially at places like Colombo and Singapore where tourists abound. It was no secret that some thousands of carats of manufactured stones were shipped annually to the East; so *caveat emptor*!

That there should be such disparity in value between objects which from many points of view are the same thing and not very different in appearance seems in the highest degree illogical and difficult to understand. The immediate reason, though it is far from a complete explanation, is that gemstones are a luxury and not a necessity, and above a minimum value, determined by the cost of the labour involved together with an appropriate percentage to cover the overhead expenses and a reasonable profit, the price is merely what the public are prepared to pay. The manufacture of synthetic stones was carried on in many factories in France, Germany and Switzerland, and later also in Great Britain, the United States and U.S.S.R. Competition was formerly keen and costs were reduced to a minimum; it need therefore cause no surprise that synthetic stones were relatively cheap, but there remains the more difficult question: why should the corresponding natural stones have been so much dearer? Owing to the uncertain prospects always attending the mining of rubies and sapphires, their prices might reasonably be expected to be higher than those of the synthetic stones, but differences are enormous. The undoubted fact is that for a treasured jewel the public feel a strong preference for stones which have mysteriously originated in the depths of the earth and owe their colouring to the haphazard addition of matter which chanced to be near by, and hold in little esteem stones which had been carefully and exactly produced in the factory; the natural stones are regarded by them as the real thing and the others as some kind of imitation.

The similar product of the organic world, the so-called cultured pearl, whose growth is likewise controlled, though not in a laboratory, is discussed in the chapter dealing with pearl (p. 476).

XV

IMITATION STONES

The beryl glass mentioned in the previous chapter marks the transition stage between synthetic and imitation stones. In synthetic stones the physical and chemical properties are the same as in the corresponding natural stones; in products such as beryl glass the chemical composition is the same as in the gemstones imitated, but the physical characters are entirely different; in imitation stones the only resemblance is in colour, and the other physical characters as well as the chemical composition are utterly unlike those of the gemstones imitated. Except that the process of forming synthetic and imitation stones is in each instance controlled by human agency, in which sense both processes may be considered to be artificial, there is no comparison between them.

Imitation stones are mostly made of glass, and imitations of the stones used in jewellery were produced in the glass-works of ancient Egypt, and possibly even earlier. We read in Pliny's *Natural History* [1] that the simulation of crystal vessels by glass had been brought to a high degree of perfection, but the value of the real article had nevertheless in no way been affected. This stability of price was the forerunner so many centuries ago of the experience of modern times: whatever be done by synthesis or imitation, the value of the natural product remains unaltered.

Glass is a hard substance, which is produced by the fusion of an acidic oxide by itself, but more usually with a basic oxide at a high temperature, from which it is allowed to cool with sufficient rapidity to prevent the formation of visible crystals. The acidic oxide is commonly silica in the shape of sand, but it may be partly boric, arsenic, antimony or phosphoric oxide, and the basic oxides are commonly soda or potash,

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[1] 'Vessels in glass have been brought to a marvellous degree of resemblance to crystal; and yet, wonderful to say, they have only tended to enhance the value of crystal, and in no way to depreciate it.' (Mire ad similitudinem accessere vitrea, sed prodigii modo, ut suum pretium auxerint crystalli, non diminuerint.) Loc. cit., book 37, ch. 2.

together with lime, magnesia, lead oxide, barium oxide, zinc oxide, thallium oxide or alumina. The so-called opal glasses are produced by the addition of fluor (calcium fluoride), cryolite (sodium-aluminium fluoride), or bone ash (calcium phosphate) or, more rarely, of tin oxide or zirconia.

Glass, being a melt and not a crystal, has an immense range in both chemical composition and physical properties, because, even supposing that the constituent components remain the same, their proportions may be graded to any extent, and the number of possible components is very large, as has just been stated. A simple glass made from pure ingredients would be colourless, but, since the sand used is never free from iron, the colour is the familiar bottle-green. To get rid of this colour, decolorizing agents, known as glassmakers' soaps, are added to the melt, the most usual ones being manganese and arsenic. Greenhouse glass, which has been exposed to strong sunlight for many years, has been found to turn mauve owing to a change in the iron constituent, corresponding to a fading, if the original colour had not been neutralized.

An equally large number of metallic oxides is available for imparting colour to glass, and by a suitable choice of glass and tinctorial agents almost any imaginable shade of colour may be attained. The oxides used and the resulting colours are as follows: iron oxides (green, brown, red); copper oxides (blue, red); cobalt oxide (blue); nickel oxide or manganese dioxide (purple in potash glass, brown in soda glass); chromic oxide (yellowish green); uranium oxide (fluorescent green or yellow); and titanium dioxide (yellow, brown). The precise shade depends not merely upon the amount of colouring matter, but also upon the glass and the conditions of melting. A magnificent ruby-red colour is produced by finely divided gold, and other colouring agents, which are not oxides, and the resulting colours are: cadmium sulphide (yellow); selenium (red); silver salts (yellow); carbon (yellowish-brown); and sulphur (yellow).

The two kinds of glass, which are commonly used for the imitation of gemstones, are the following:

(1) Crown, window or bottle glass: silica, potash or soda, and lime, with ferric oxide and titanium oxide as colouring agents. The refractive index ranges from 1·52 to 1·54, and the specific gravity from 2·53 to 2·57 for the material with little or no colour; if much ferric oxide be added to colour the stones, the values are considerably higher, the range for the refractive index being 1·57 to 1·59, and for the specific gravity 2·66 to 2·75.

(2) Flint, or lead glass: silica (formerly provided by crushed flints,

giving the name to the glass), potash or soda, lead oxide. In the material generally used for imitation stones the refractive index ranges from 1·58 to 1·68, and the specific gravity from 3·15 to 4·15. Lead glass can be made with a refractive index as low as 1·52, the corresponding specific gravity being 2·70, and very much denser glass is supplied for optical purposes, but the latter kind is very soft and consequently not very serviceable for ornamental wear. The lead glass sometimes used for diamond imitations has a composition of 38·2 per cent of silica, 53·3 of lead oxide and 7·8 of potassium carbonate, with small quantities of other substances. It comes at the higher end of the range given above. Such material was formerly known as strass, a term said to be derived from the name of the original user, Josef Strasser, but this word is now obsolescent.

These two groups pass into others by complete or partial substitution. Thus, if some of the silica in crown-glass be replaced by boric oxide, we have a borosilicate-crown, or, by phosphoric oxide or fluor, phosphate-crown or fluor-crown. Again, lime in crown-glass may be replaced by barium oxide or zinc oxide, yielding barium-crown or zinc-crown; and the lead oxide in flint-glass may be replaced by barium oxide or titanium oxide, yielding barium or titanium flints.

Borosilicate glass has a refractive index and specific gravity of about 1·50 and 2·36. The values for the titanium glass are 1·47 to 1·49 and 2·40 to 2·52, and for opal glass 1·44 to 1·46 and 2·07 to 2·15.

Cheap glass imitations are either a crown-glass or a flint-glass with refractive indices about 1·53 or 1·63. The addition of lead increases the refraction and the colour-dispersion, and these stones, when new and unspoilt, are very beautiful if properly cut, but unfortunately they are very soft and can be scratched even by window-glass. If rubbed in the course of wear, they speedily lose their polish; moreover, they are susceptible to attack by the sulphurous fumes in the smoky atmosphere of towns, and are apt therefore after a time to turn an unattractive shade of brown. Since common paste is not highly refractive enough to give satisfactory results when cut as brilliants, the base of such stones is often coated with quicksilver (mercury), or in the case of older jewellery covered with foil in the setting, the object being to reflect back through the stone the light which would otherwise escape at the base.

Imitation stones are easy and cheap to fashion. They are moulded to shape and have not therefore to be cut, and any polishing required is soon done because of their comparative softness.

No difficulty is experienced in distinguishing glass imitations from gemstones. The much lower hardness readily distinguishes paste from the natural stones which it simulates. The relative colour-dispersion of glass is greater than it is for gemstones, and paste stones show hardly any colour to the shadow-edges seen in the refractometer.[1] Being necessarily singly refractive, such stones cannot be dichroic, as many coloured gemstones are, and their refractivity and specific gravity seldom accord even approximately with those of the natural stones imitated.

GLASS GROUPS

	Refractive Index	Specific Gravity
Flint, lead	1·58–1·68	3·15–4·15
Calcium-iron	1·57–1·59	2·66–2·75
Calcium	1·52–1·54	2·53–2·57
Borosilicate	1·50	2·36
Titanium-iron	1·47–1·49	2·40–2·52
Opal	1·44–1·46	2·07–2·15

It will be noticed that the ranges of refractivity of crown-glasses (calcium and calcium-iron) and of the flint-glasses overlap, although the former is on the whole lower, but that the higher specific gravity of the latter group may be used to remove any doubt.[2] From the jewellers' point of view the precise nature of the glass of an imitation stone is unimportant.

In order to meet the test for hardness in a mounted stone the doublet was devised. Such a stone is composed of two different substances: the crown consists of quartz or other inexpensive, natural, hard stone, and the base of coloured glass. It will be remembered that all the light that has emerged through the top of the stone must have traversed the base near the culet, and the stone will therefore appear from the top to be of whatever colour the base is; it is only by looking through the crown sideways that one can detect its lack of colour. When the imitation, say of

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[1] If n and n' be the refractive indices of the paste stone and the dense glass of the refractometer respectively, then at total reflection $n = n' \sin i$, where i is the angle of total reflection. The colour dispersions are related by the equation, $\frac{dn}{n} - \frac{dn'}{n'} = \frac{n'}{n} \cos i \,.\, di$, and, if the relative dispersions, $\frac{dn}{n}$ and $\frac{dn'}{n'}$, be equal, $di = 0$, and the edge of the dark field seen in the refractometer will be uncoloured.

[2] Readers interested in glasses and the means of distinguishing them should consult the paper by F. A. Bannister, 'A relation between the density and refractive index of silicate glasses, with application to the determination of imitation gemstones,' *Mineralogical Magazine*, 1929, vol. XXII, pp. 136–54.

sapphire, is intended to be more exact, the crown is made of a real sapphire, but one deficient in colour, the requisite tint being provided by the paste, forming the base of the doublet. At the present time the only doublets that are common consist of a thin slice of almandine, forming the table, to which is fused a glass back of the appropriate colour for ruby, sapphire or emerald. The almandine usually has a refractive index of nearly 1·79, and under the microscope often shows typical, needle-like, intersecting inclusions; at the same time a layer of bubbles is visible at its junction with the glass.

In case the base should also be tested for hardness, the triplet has been devised. The base now is also made of a real stone, and the colour is derived from a thin girdle section, which is hidden by the setting. Stones, such as sapphires and emeralds, of indifferent colour are sometimes slit across the girdle and the interior surfaces are polished; colouring matter is introduced with the cement which is used to reunite the two portions of the stone. In the so-called *émeraude soudé* (soldered emerald) a crown and base of rock-crystal are united by a green transparent cement to simulate a real emerald; in modern types the joins appear to be made by sintering. A further variety, *soudé sur spinelle*, has synthetic spinel in place of rock-crystal. All such imitations are easily detected by placing the stone in an oil, so as to enable the interior to be more readily inspected, when the surfaces separating the different portions of the composite stone will be visible. The cemented types may fall to pieces when immersed in an appropriate solvent, such as boiling water, alcohol or chloroform: a sintered join, however, is unaffected by such solvents.

The glass-like plastics, especially the methacrylate and amine plastics (pp. 510, 511), provide clear limpid material, colourless or of various lovely tints. Inasmuch as they take the impression of moulds better than glass does, the edges of the facets are appreciably sharper. There can be no risk of confusing them with gemstones or even glass if they be unmounted, because their specific gravity is so low, slightly under 1·20, that mere handling of them suffices to betray their nature. If they be mounted, it will be found that as regards refractivity they are lower than any gemstone which they may resemble in colour. Moreover, they are very soft, their hardness being only about $2\frac{1}{2}$ of Mohs's scale, and, being so much less diathermous than gemstones, they appear warm to the touch.

There is, of course, not the same temptation to attempt the imitation of non-transparent gemstones, such as chalcedony, turquoise, lapis-lazuli and jade, since the value of the genuine stones is comparatively small and the possible financial gain is correspondingly restricted. Nevertheless, these gemstones are imitated, probably in the East, and fraudulent pieces may be met. The material used is varied, and may be bone, celluloid or a clay-product (porcelain, etc.) with the addition, if necessary, of a colouring agent. There is usually no difficulty in distinguishing such imitations by testing the hardness and the specific gravity; if some uncertainty is still felt, a few scrapings may be taken and examined under the microscope.

An imitation of lapis-lazuli, made from sintered synthetic blue spinel, has been produced in Germany; this, also, differs from the genuine material in its physical properties (p. 438). By special heat-treatment synthetic spinel has been given a sheen like that of moonstone. The imitations of pearl are considered in the chapter dealing with pearl.

XVI

FORMATION AND GEOGRAPHICAL DISTRIBUTION

In the opening line of this book beauty is said to be one of the three cardinal virtues of a perfect gemstone. It is the one first mentioned, and might, indeed, be aptly described as the foremost of the three, for it is the beauty resulting from the colour or the limpidity or a combination of the two that first attracts the eye to a stone. These qualities are intimately bound up with the nature of the stone's structure; it therefore follows that, apart from such gemstones as opal and turquoise, those which are prized for ornamental wear represent the finest examples of crystallization which nature affords. The most important primary sources of relatively large crystals are the different kinds of *igneous* rocks which make up part of the earth's crust. These rocks have formed through the crystallization of molten rock material (magma) which has arisen from greater depths and has consolidated near to, or at, the earth's surface at temperatures generally within the range of 950° to 450° C. The lavas erupted by volcanoes at the present day provide examples of such crystallization, but since they cool rapidly at the surface, they are mostly very fine-grained, and thus unlikely to be a source of desirable gem material. Indeed, in some cases the lava cools so rapidly that it solidifies without crystallizing, providing the natural glass, obsidian (p. 421). Gem material is more likely to occur in igneous rocks which have consolidated deeper in the crust, either in large deep-seated masses far below the earth's surface (*plutonic* rocks) or in veins and offshoots (*dykes*) running out from these masses through fissures in the surrounding rocks. Under these conditions the magma cools more slowly and crystals have time to grow larger.

Much of the primary magma which rises within the crust has a composition close to that of the common volcanic rock, basalt. Chemically it consists of about 50 per cent silica (SiO_2), with alumina (Al_2O_3), lime (CaO), magnesia (MgO) and iron oxides (FeO and Fe_2O_3) next in importance. Such a silica-content is low in comparison with certain other types of rock material and is described as basic. When such a magma begins to crystallize, the first mineral to separate in quantity is a magnesian olivine (peridot). This contains an even lower proportion of silica than the magma as a whole, and if the crystals constitute the greater part of a resulting rock, this (called, appropriately, a peridotite) will be ultrabasic in composition. Rock of this kind fills the diamantiferous pipes of South Africa (p. 286); the magnesian garnet, pyrope (p. 333), is another mineral low in silica which may crystallize with the olivine.

Removal from the magma of such ultrabasic minerals leaves the remaining melt much enriched in silica, and later products of this type of igneous activity are likely to be rocks which are increasingly acid (that is, richer in total silica-content). The silica-content of a highly acid melt (70 per cent or more) is such that much of it crystallizes out as free silica in the form of quartz. Concurrently with the increasing silica-content there will also be an increasing concentration of many of the rarer constituents, lithium, beryllium, boron and the like, which play no part in the earlier crystallization. There will be a concentration, too, of the highly volatile constituents such as fluorine, chlorine and hydroxyl; these play an effective part in lowering the viscosity of the melt in the later stages, allowing greater freedom of growth of large crystals. Thus it is that one often finds as a last phase of activity the development of the coarsely-crystalline dykes known as *pegmatites*, with large crystals of quartz, feldspars and mica, which are particularly favourable for the production of gem material such as tourmaline, beryl, topaz and spodumene. The variegated crystals of tourmaline which are so characteristic of this gemstone show how conditions during crystallization may vary though remaining favourable for growth.

Except in the remarkable case of the diamantiferous pipes in South Africa, which are discussed in a later chapter, it is seldom commercially profitable to exploit hard, unweathered rock for gem material. This is where we see the advantage of the second virtue of a perfect gemstone—durability. The gem material contained in a rock is unaffected by its weathering, and may then be more easily extracted from the softened matrix. Moreover, owing to their superior hardness and greater density, when the rock becomes completely disintegrated and is carried away by water, they survive more or less unscathed the vicissitudes which have scattered their original associates, and become concentrated in the beds of past or present streams and rivers. Even they may show the rounding of edges and roughening of faces due to the long continued rubbing with transient neighbours, while rolling along their watery way.

Such secondary deposits of sands and gravels (alluvials) are important sources of gem materials, including not only minerals derived from the primary igneous occurrences which we have just noted but also others, such as sapphire, ruby and spinel, derived from metamorphic rocks to be described below. Vast quantities of diamond are won from alluvials, but even excluding this exceptional mineral, gem gravels probably account for about one-half of the value of total gem production.

Sands and gravels are one type of *sedimentary* rock, the general term for all rocks which are composed of material, derived by weathering from a previously existing rock, which has been transported and redeposited by the aid of water. (Clays and shales are other examples of sedimentary rocks, though of little importance in our present discussion.) In addition to the insoluble material, which is transported in suspension and deposited mechanically, soluble products of rock decomposition pass into solution and are eventually deposited by crystallization to yield chemical deposits such as gypsum and some kinds of limestone. Some of this dissolved material may be recovered through the biological activity of organisms, as in the growth of coral and the development of a pearl.

For yet another important mode of genesis of gem materials we must return to further consideration of igneous activity. When a large mass of molten magma is emplaced amongst the sedimentary country-rocks of the crust these latter are heated up and undergo a process of *contact metamorphism* whereby they are largely or wholly recrystallized. Limestones are particularly sensitive to this action. The gem materials formed, such as ruby and spinel, may consist entirely of material present in the original rock; ruby represents corundum derived from original clay impurities in the limestone, whilst the magnesia content of the spinel is derived from an original content of dolomite, calcium-magnesium carbonate. Frequently, however, volatile constituents pass out from the igneous body into the surrounding rock and take part in the formation of new minerals, as in the development of lapis-lazuli. These volatile constituents, too, may react on the igneous rock itself, as in the conversion of olivine into serpentine and the deposition, in cavities, of minerals such as thomsonite, opal and agate. Contact metamorphism is usually essentially local, being confined to the near neighbourhood of the igneous contact, but in some circumstances the country rock is recrystallized over much wider areas under the action of *regional metamorphism*. Though not as important to us as contact metamorphism, this process may give rise to such gem materials as nephrite, kyanite, staurolite and sillimanite. As with gems of primary igneous origin, however, many of these metamorphic products are recovered mainly from secondary gravels in which they have been concentrated.

Although gemstones are comparatively widespread throughout the world,[1] the regions in which they are sufficiently concentrated to justify systematic exploitation are relatively few. Published statistics of the output of various countries are very incomplete, and it is impossible to do more than make very general statements. In a tabulation of production of gemstones by value the chief producer of diamond will hold a preponderant position, owing to the surpassing importance of this stone both as a jewel and in industry. The continent of Africa, by reason of the diamond production from Congo, Angola, Ghana, South Africa and South-West Africa, Tanganyika, and Sierra Leone, is probably responsible for more than 90 per cent by value of the world's gemstones. South America, producing diamond from Brazil and British Guiana and emerald from Colombia, seems likely to rank second, perhaps almost equalled by Asia, each with a percentage value of 2–3. The rapidly rising output of diamond from the U.S.S.R., however, may soon place the latter continent in the lead.

If we exclude diamond and confine attention to the less precious stones, Asia probably ranks first in importance by reason of the output of rubies and sapphires from Burma, Siam, Ceylon, and India. The value of amber production from the Baltic coast, from Rumania, and from Sicily determines the position of Europe, whilst the variety of gemstones found in Brazil is similarly significant for South America. The North American continent has produced a wide range of the less precious materials, but no large quantity of the more valuable stones; the output of turquoise would probably be most important in determining the percentage production by value.

The percentage annual production in value of the various gemstones is given in the following table: they must, of course, be regarded as approximate, although the importance of diamond is always outstanding.

PERCENTAGE PRODUCTION IN VALUE OF GEMSTONES, BY SPECIES

Diamond	94·3	Rock-crystal	0·2
Sapphire	1·5	Aquamarine	0·2
Amber	1·0	Tourmaline	0·1
Emerald	0·7	Amethyst	0·1
Ruby	0·5	Chalcedony	0·1
Jadeite	0·4	Garnet	0·1
Turquoise	0·3	Nephrite	0·1
Opal	0·3	Other species	0·1

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[1] See Sydney Hobart Ball (1879–1949), 'The Geologic and Geographic Occurrence of Precious Stones,' *Economic Geology*, 1922, vol. xvii, pp. 575–601.

In the next table is given a list of the gemstones which have been produced in the principal countries. The list is not comprehensive; it is restricted to species which at least occasionally have found their way into commerce, and does not include every species found which might occasionally yield gem material.

GEMSTONES OCCURRING IN THE PRINCIPAL COUNTRIES

British Isles: quartz (rock-crystal, smoky-quartz, cairngorm, citrine, amethyst), chalcedony (agate), fluor ('blue-john'), haematite, amber, jet.

Norway: beryl, feldspar.

U.S.S.R.: diamond, beryl (emerald, aquamarine), chrysoberyl (alexandrite), phenakite, tourmaline, garnet (grossular, andradite), turquoise, quartz, chalcedony, labradorite, nephrite, lapis-lazuli, obsidian, dioptase, hemimorphite, feldspar (sunstone), topaz.

Germany: topaz, garnet (almandine, pyrope), corundum (sapphire), peridot, quartz (amethyst), chalcedony (chrysoprase, agate), diopside, fluor, amber.

France: zircon, variscite, quartz (rock-crystal, amethyst, citrine).

Switzerland: sphene, quartz (rock-crystal, smoky-quartz).

Spain: quartz (amethyst, citrine), haematite, jet.

Egypt: beryl, peridot, turquoise.

Angola: diamond, corundum.

Congo: diamond.

Equatorial Africa (Chad, Central African Republic, Gabon): diamond, tourmaline, kyanite, staurolite, zircon, chrysoberyl, topaz, dioptase.

Ghana (Gold Coast): diamond.

Sierra Leone: diamond, garnet (andradite), corundum (ruby), zircon.

Southern Rhodesia: diamond, emerald, chrysoberyl, topaz, garnet (pyrope), tourmaline.

Tanganyika: diamond, garnet (almandine, pyrope), quartz (amethyst), phenakite, feldspar (moonstone), euclase.

South Africa: diamond, garnet (grossular, pyrope), beryl (emerald), quartz (amethyst, rose-quartz, cairngorm, hawk's-eye, tiger's-eye), enstatite.

South-West Africa: diamond, beryl, tourmaline, topaz, quartz (rose-quartz), chalcedony (chrysoprase, bloodstone), cordierite, lazulite.

Madagascar: spodumene (kunzite), corundum, beryl, tourmaline, garnet, quartz, chalcedony, topaz, spinel, chrysoberyl, cordierite, feldspar, zircon, kornerupine, scapolite, danburite, hambergite, rhodizite.

India: diamond, corundum (sapphire), chrysoberyl (cymophane), beryl (emerald), garnet (almandine), tourmaline, quartz (rock-crystal, amethyst, rose-quartz aventurine quartz), chalcedony (agate), kyanite, euclase, serpentine (bowenite), apatite, cordierite, feldspar (amazonstone), zircon, rhodonite.

Burma: corundum (ruby, sapphire), spinel, jadeite, zircon, quartz, beryl, chrysoberyl, topaz, peridot, scapolite, apatite, fibrolite, tourmaline, amber (burmite), lapis-lazuli, diopside, enstatite, kyanite, danburite.

Ceylon: corundum (sapphire, ruby), chrysoberyl (alexandrite), spinel, zircon, topaz, garnet, beryl, tourmaline, sphene, rutile, cordierite, fibrolite, andalusite, diopside, apatite, quartz (amethyst, cat's-eye), feldspar (moonstone), kornerupine.

Siam: corundum (sapphire, ruby), zircon.

Persia: turquoise.

Afghanistan: corundum (ruby), lapis-lazuli.
Australia: diamond, corundum (ruby, sapphire) , opal, beryl (emerald), zircon spinel, topaz, garnet, quartz, chalcedony, turquoise, peridot.
New Zealand: nephrite, opal, chalcedony, serpentine (bowenite).
China: nephrite, quartz (amethyst, smoky-quartz), chalcedony (cornelian agate).
Cambodia: corundum (sapphire), zircon.
Japan: quartz (rock-crystal, amethyst, rose-quartz, jasper, plasma).
Indonesia: diamond.
Canada: peridot, tourmaline, apatite, turquoise, quartz (amethyst), chalcedony (agate), feldspar (labradorite).
Newfoundland: labradorite.
United States of America: diamond, corundum (sapphire), turquoise, tourmaline, opal, chalcedony (agate), beryl, feldspar (amazonstone, sunstone), lapis-lazuli, nephrite, rhodonite, topaz, spodumene (kunzite, hiddenite), pollucite, zincite, variscite, dumortierite.
Mexico: opal, garnet, quartz (amethyst, rock-crystal).
Honduras: opal.
Colombia: beryl (emerald), corundum (ruby, sapphire), garnet, chalcedony (cornelian, agate).
British Guiana: diamond.
Brazil: diamond, beryl, chrysoberyl, topaz, tourmaline, garnet, quartz (amethyst, rock-crystal), chalcedony (agate), andalusite, euclase, nephrite, phenakite, scapolite, brazilianite.
Argentina: garnet (pyrope), beryl, quartz (rose-quartz), chalcedony (agate).

XVII

BIBLE STONES

The use of gemstones to adorn the person, to enhance the dignity of high estate and to impart brilliance to ceremonial rite goes back to the far-distant past. Then as now gemstones were held in high esteem and were amassed by kings and potentates not only to wear in evidence of the greatness of their position but also to hoard as treasure to meet the cost of rule or to provide the sinews of war. Inasmuch as gemstones are both portable and durable, it is not surprising to find that, although they were not mined in Palestine, they were from early times introduced into the country, mainly through the city of Tyre.

In the Bible we find that valuable gemstones were used for the adornment of the Breastplate, which was worn by the High-priest when ministering to Jehovah. The term breastplate is perhaps a little misleading, because we have come to regard it as meaning a piece of armour, which before the days of firearms was used in war to protect the body but is now relegated to ceremonial occasions. Actually it was the linen bag containing the mysterious Urim and Thummim, by means of which the High-priest was enabled to interpret the will of Jehovah on matters affecting the welfare of Israel. This bag was adorned with gemstones, twelve in number and probably flat and oval in shape, which were mounted in gold filigree settings and were severally engraved with the names of the twelve tribes. The gemstones of the Breastplate are described in the Authorized Version of the Bible, issued in 1611, as follows:

Exodus, ch. 28—

17. And thou shalt set in it settings of stones: even four rows of stones: the first row shall be a sardius, a topaz, and a carbuncle: this shall be the first row.
18. And the second row shall be an emerald, a sapphire, and a diamond.
19. And the third row a ligure, an agate, and an amethyst.
20. And the fourth row a beryl, and an onyx, and a jasper: they shall be set in gold in their inclosings.
21. And the stones shall be with the names of the children of Israel twelve, according to their names, like the engravings of a signet: every one with his name shall they be according to the twelve tribes.

Besides this description, which in the Hebrew original perhaps goes back to about 1500 B.C., four others have come down to us: in the Septuagint Version, the Greek translation which was made at Alexandria in the early half of the third century B.C.; in the Vulgate Version, the Latin translation made by St Jerome [1] about A.D. 400; and in Josephus's[2] two works, the Jewish Wars, written originally in Hebrew about A.D. 75, shortly after the destruction of Jerusalem, and subsequently translated into Greek, and the Jewish Antiquities, written in Greek about A.D. 93.

The gemstones and their position on the Breastplate as described in the five versions are given in the following table, the English equivalent always being used:

GEMSTONES ON THE HIGH-PRIEST'S BREASTPLATE

FIRST ROW

Authorized	sard	topaz	carbuncle
Septuagint	sard	topaz	emerald
Vulgate	sard	topaz	emerald
Jewish Wars	sard	topaz	emerald
Jewish Antiquities	sardonyx	topaz	emerald

SECOND ROW

Authorized	emerald	sapphire	diamond
Septuagint	carbuncle	sapphire	jasper
Vulgate	carbuncle	sapphire	jasper
Jewish Wars	carbuncle	jasper	sapphire
Jewish Antiquities	carbuncle	jasper	sapphire

THIRD ROW

Authorized	ligure	agate	amethyst
Septuagint	ligure	agate	amethyst
Vulgate	ligure	agate	amethyst
Jewish Wars	agate	amethyst	ligure
Jewish Antiquities	ligure	amethyst	agate

FOURTH ROW

Authorized	beryl	onyx	jasper
Septuagint	chrysolite	beryl	onyx
Vulgate	chrysolite	onyx	beryl
Jewish Wars	onyx	beryl	chrysolite
Jewish Antiquities	chrysolite	onyx	beryl

The description in the Jewish Wars, which in an English translation is as follows, is not so precise as in the other sources, and it has been assumed above that the order of the gemstones in the text corresponded to the arrangement on the Breastplate:

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[1] Eusebius Hieronymus (Ἱερώνυμος), A.D. 340–430.

[2] Flavius Josephus, A.D. 37–100(?).

On the other part there hung twelve stones, three in a row one way and four in the other: sard, topaz, emerald, carbuncle, jasper, sapphire, agate, amethyst, ligure, onyx, beryl, chrysolite. (Book V, ch. 5, par. 7.)

We notice that, ignoring the order, the species of gemstones mentioned in the several versions are identical with two exceptions: diamond in the Authorized Version replaces chrysolite in the others, and sardonyx appears in the Jewish Antiquities instead of sard. The diamond in the Authorized Version clearly could not have been the gemstone known by that name to-day, because the latter would have been too hard to be engraved with the name of one of the tribes, apart from the fact that diamonds of the size required for the Breastplate are uncommon; it is, indeed, doubtful if our diamond were generally known much before about A.D. 1000. Sardonyx, however, might well have been the more correct name if the piece had a streak in it, and may therefore be considered as an alternative to sard.

We need feel no surprise at the want of coincidence of the gemstones and their arrangement in the several versions. Indeed, if we remember that before the invention of the printing-press and the later mechanical means of reproducing documents all publications were laboriously copied by hand, the wonder is that the concordance is as good as it is. It must, too, not be forgotten that oriental languages are read from right to left, that is in the direction opposite to that used in occidental languages; the difference in the order of the gemstones in the third row in the two accounts written by Josephus may be due to this cause. Another explanation of the discrepancies between the several descriptions may be that they do not refer to the same object. History records that on several occasions before the final disaster of A.D. 70 Jerusalem suffered the ravages of war, and, unless the Breastplate had been safely hidden, such a valuable and famous object was sure to be amongst the loot removed by the conqueror. If that happened, it would have been replaced by another, since the Breastplate formed an integral part of the Jewish worship; but it might not have proved practicable to obtain stones precisely similar to those in the Breastplate which had been seized. That there must have been some such replacement is suggested by the difference in the gemstones mentioned as set in gold on the shoulders of the vestment, called the Ephod, so as to form buttons, from which the Breastplate was suspended by linen bands. In the Authorized Version the stones are said to be onyx.

Exodus, ch. 28—

9. And thou shalt take two onyx stones, and grave on them the names of the children of Israel:

10. Six of their names on one stone, and the other six names of the rest on the other stone, according to their birth.

Exodus, ch. 39—

6. And they wrought onyx stones, inclosed in ouches of gold, graven, as signets are graven, with the names of the children of Israel.

7. And he put them on the shoulders of the ephod, that they should be stones for a memorial to the children of Israel; as the Lord commanded Moses.

The Septuagint equivalent is emerald, but Josephus calls them sardonyx. Such striking differences in colour suggest that the stones must have been different.

In his dream Ezekiel appears to have had in mind the stones of the Breastplate, when he described the splendour of the King of Tyre, since all the nine stones mentioned are among those of the Breastplate, though not in the order in which they appear there.

Ezekiel, ch. 28—

13. Thou hast been in Eden the garden of God; every precious stone was thy covering, the sardius, topaz, and the diamond, the beryl, the onyx, and the jasper, the sapphire, the emerald, and the carbuncle, and gold. . . .

The Vulgate gives the same nine stones with the substitution of chrysolite for diamond, but in a different order: sard, topaz, jasper, chrysolite, onyx, beryl, sapphire, carbuncle, emerald. In the Septuagint, on the other hand, all twelve stones of the Breastplate are mentioned (together with the precious metals) and they are in the same order in both instances: sard, topaz, emerald, carbuncle, sapphire, jasper, silver, gold, ligure, agate, amethyst, chrysolite, beryl, onyx.

The three stones omitted in the Authorized and Vulgate Versions are those of the third row: ligure, agate, amethyst. This omission may have been due to miscopying.

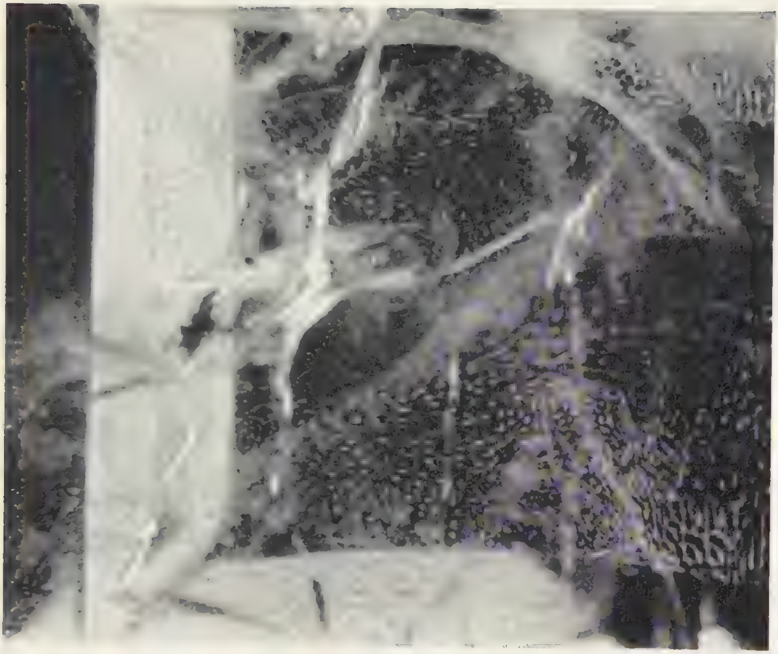
Another series of twelve stones appear as the foundations of the Heavenly Jerusalem, which do not accord with those that adorned the High-priest's Breastplate, chrysolite, chalcedony, sardonyx, chrysoprase and jacinth taking the place of diamond, carbuncle, ligure, agate and onyx.

Revelation, ch. 21—

19. And the foundations of the wall of the city were garnished with all manner of precious stones. The first foundation was jasper; the second, sapphire; the third, a chalcedony; the fourth, an emerald;

20. The fifth, sardonyx; the sixth, sardius; the seventh, chrysolyte; the eighth, beryl; the ninth, a topaz; the tenth, a chrysoprasus; the eleventh, a acinth; the twelfth, an amethyst.

21. And the twelve gates were twelve pearls; every several gate was of one pearl; and the street of the city was pure gold, as it were transparent glass.

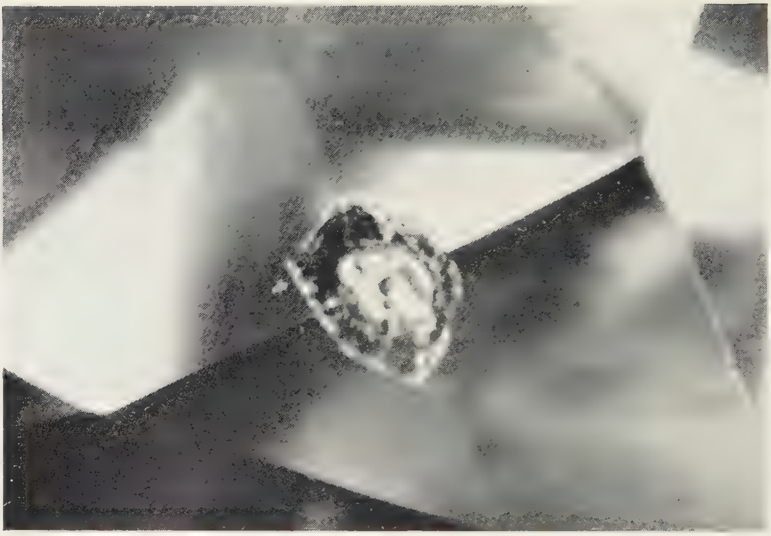


1. Typical liquid feather. × 20

2. Enlargement of the ramifying canals of the feather.

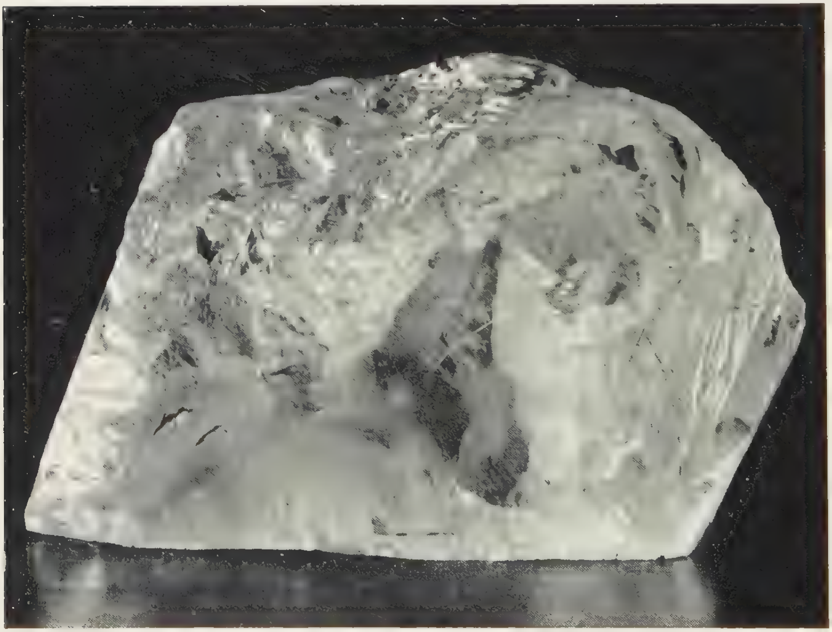
(Photos by E. Gübelin)

XV. SYNTHETIC EMERALD



1. Inclusion, in diamond, of a fragment of kimberlite which itself encloses a minute octahedron of diamond. × 80

(Photo E. Gübelin



2. 'Cullinan' diamond

(*Actual Size*)

Although nearly all the gemstones mentioned in the Bible bear names which are still in use, it by no means follows that the species represented are the same, and, indeed, it is almost certain that in many instances the name has become transferred from one species to another entirely different. Before the discovery of the method of cutting stones they were merely roughly shaped and polished, and pieces were valued for their colour and texture, and not for their transparency; the species were therefore not those which are accounted precious to-day. Since the High-priest's Breastplate, which was taken to Rome after the destruction of Jerusalem, has disappeared and the other two series of stones figured in dreams, we have nothing material available to enable us to identify the mineral species represented by the several names. Possibly a clue is provided in certain instances by the root of the equivalent word in Hebrew, and we may thus feel reasonably confident that sard, emerald and sapphire mean a red, green and blue stone respectively. To ascertain the meaning of the various names, it becomes necessary to refer to writers on minerals of about the same epoch. The earliest work which has survived is the one on stones in Greek by Theophrastus,[1] who died not long before the Septuagint Version was begun. A more extensive work was the great treatise on natural history in Latin by Pliny the Elder (p. 25), published in A.D. 77.

All the names of stones appearing in the Authorized Version were taken from the original Greek through the Latin with but literal changes, since no suitable English words existed. The Greek and Latin forms of the names are closely related, except in the case of carbuncle, which is derived from the diminutive form of *carbo* (spark), the Greek equivalent being *ἄνθραξ*. Since in ancient times stones were distinguished mainly by colour and to a lesser extent by hardness, many belonging to different mineral species were confused, and others supposed to be different were but varieties of the same mineral species. It is possible that the following names included the stones still so known to-day: amethyst, emerald, beryl, sard, onyx, sardonyx. Others are almost certainly different. Thus, sapphire from Pliny's description was our lapis-lazuli. Topaz was a green stone and may have been our olivine. Chrysolite was a yellow stone, jacinth was a pale-blue one, chrysoprase a green one and jasper also a green one, contrary to their use to-day. Carbuncle included probably all the red stones—ruby, spinel and garnet, but in the Breastplate it would most likely have been the last named, because it was soft enough to be engraved. Chalcedony appears to have been a green stone,

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[1] *Θεόφραστος* (divine speaker), pupil and literary heir of Aristotle, died 287 B.C. at the age of 85, or according to some accounts, 107.

and certainly was not the cryptocrystalline form of quartz so called to-day. One name, ligure, has entirely dropped out; it appears to have been a fairly hard, yellowish stone, possibly a zircon.

In an early passage of the Bible what seems to be a precious stone is mentioned, which presents a perplexing puzzle.

> Genesis, ch. 2—
>
> 12. And the gold of that land is good: there is bdellium and the onyx stone.

Bdellium is repeated in a later passage; but does not appear again in the Bible.

> Numbers, ch. 11—
>
> 7. And the manna was as coriander seed, and the colour thereof as the colour of bdellium.

There is little clue to the meaning of the word, which is the Latin form of the Greek *βδέλλιον*. Since manna was probably a lichen (*Lecanora esculenta*), which is still used as a food in North Africa, and forms small, greyish, or whitish lumps, bdellium might have been a lump of resin or even a pearl of similar appearance.

The alabaster of the Bible was an onyx-marble (calcite), and not the variety of gypsum which is so called to-day. Crystal, amber, coral and pearl had the same meaning then as now, but in certain passages in the Authorized Version the translation should have been glass instead of crystal and crystal instead of pearl.

XVIII

HISTORICAL STONES

In the chapter on the unit of weight it was pointed out that prior to the general adoption of the international unit of one-fifth gram the carat-weight in use in different parts of the world varied not only with the country but even with the date also. No great reliance can therefore be placed upon the weights quoted for old stones which have disappeared or upon the weights quoted for such before they were cut; moreover, the uncertainty about the weights is equalled by the uncertainty about the accuracy of the original weighings.

In order not to add still further to the confusion attending the weights quoted for the old stones, we have, subject to the cautionary note sounded above, repeated the weights usually given, and have left open the standard upon which they were based. Where the weights are expressed in metric carats, they may be trusted, either because they were determined in the international unit or because the unit in which they were originally weighed is definitely known.

Despite, however, the uncertainty about the accuracy of the old figures they are at least an approximation and do serve to provide some indication of the size of these famous old stones.

A. DIAMONDS

The number of diamonds which exceed 100 carats in weight when cut, although vastly increased after the discovery of the South African mines, is still limited. Their costliness, apart from their size, renders them something more than mere ornaments; in a condensed and portable form they represent great wealth and all the potentiality for good or ill thereby entailed, and have played a large, if sinister, rôle in the moulding of history. In bygone days when governments were despotic the possession of a splendid diamond in weak hands but too often precipitated the aggression of a greedy and powerful neighbour, and plunged whole countries into the horrors of a ruthless and bloody war. In more civilized times a great diamond has often been pledged as security for money to replenish an empty treasury in times of stress.

The ambitions of Napoleon, for instance, might have received a setback but for the funds raised on the security of the famous Pitt diamond. A century later, too, when thrones toppled and revolution was abroad, those unhappy beings who had to flee from their homes to save their lives were fortunate if they could bear with them caskets of jewels, because such are readily negotiable anywhere, whereas securities and notes for money are but too often hardly worth the paper on which they were printed and the precious metals are in relation to their weight of far less value. The history of famous stones—often one long romance—is full of interest, but space will not permit of more than a brief sketch here.

Among the diamond-producing countries India is pre-eminent as the birthplace of historic diamonds, largely because for so long a period in history it alone supplied the civilized world with this highly-prized gemstone. Brazil has yielded many diamonds, but few of them large. South Africa, on the other hand, has proved so prodigal in diamonds of all sizes that only the very exceptional ones have been honoured with a name, and smaller stones, many of which would have aroused excitement had they come to light in distant days when diamonds were comparatively rare, now have attracted hardly even casual notice in the newspaper press of the day.

i *INDIA*

I KOH-I-NUR

The famous diamond known as the Koh-i-nur is said to have been discovered in the Golconda mines in southern India, and in its original state to have weighed 800 carats. Its history is known as far back as 1304, when it fell into the hands of the Mogul Emperors, and legend traces it back some four thousand years previous to that date. It remained at Delhi in the possession of successive Emperors, and is said to have embellished Shah Jahan's celebrated Peacock Throne. Eventually with the immense booty captured by Nadir Shah, when he sacked Delhi in 1739, following upon his successful invasion of north-west India, it was taken by the conqueror back to Isfahan, in Persia. After his assassination in 1747 the empire which he had founded fell to pieces, as is not infrequently the aftermath of despotic government. The Afghan, Ahmad Abdali, who had made an unsuccessful attempt to seize the vacant throne, somehow gained possession of the great diamond and the Timur Ruby during the confusion at Isfahan, and took them with him when he marched to Kandahar and set up the kingdom of Afghanistan under his rule. He adopted the name Durr-i-Dauran

(Pearl of the Age), from which his family became known as the Durrani. He died in 1773, and was succeeded by his son Timur, who removed his capital to Kabul, the treasure going with him. Upon the latter's death in 1793 a long period of disturbance ensued. His successor was the fifth of his twenty-three sons, Zaman Mirza. Owing to the difficulty of maintaining his position he granted Lahore to the Sikh adventurer, Ranjit Singh, but the same year he was ousted from the throne by his brother, Mahmud. He in his turn was deposed in 1803 in favour of another brother, Shuja-ul-Mulk. The latter's rule proved very unpopular, and in 1813 he had to flee for safety to Lahore, taking his jewels with him. The Raja, Ranjit Singh, allowed him shelter, but took possession of the jewels, including the Koh-i-nur.

The great diamond remained in the Toshakhana at Lahore until the annexation of the Punjab in 1849 at the end of the Second Sikh War, when the treasure came into the possession of the East India Company, on whose behalf the Koh-i-nur was presented by Lord Dalhousie to Queen Victoria on 3 June 1850. It was shown at the Great Exhibition of 1851. At this date the stone still retained its original Indian form, but in 1852 it was recut under the supervision of James Tennant (1808–81), Mineralogist to Queen Victoria, into the form of a shallow brilliant (fig. 112), the weight being thereby reduced from 191 to 108·9 metric carats. Much doubt has been felt as to the wisdom of this course, and it has been subjected to severe criticism. In its new form the diamond has still not gained the correct proportions of a brilliant, and little, if any, improvement was effected in its fire; but the gravest objection is that with the loss of the original shape has vanished a great deal of its old historical interest, in which it was surpassed by no other stone.

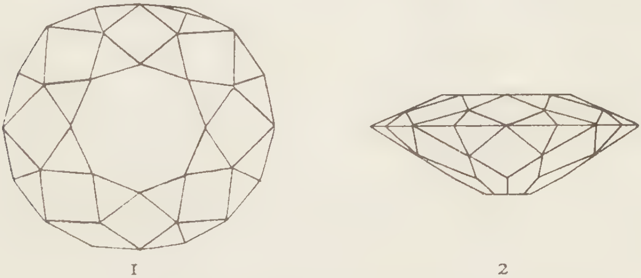
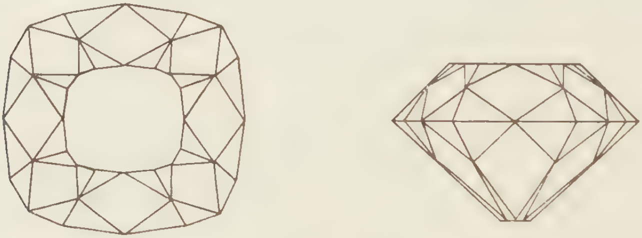

1 2

FIG. 112.—Koh-i-nur diamond: (1) crown, (2) side.

The Koh-i-nur was worn by Queen Victoria as a brooch, but at her death it was transferred to the British regalia, and was set in the centre of the front crosspatée of the State Crown, first of Queen Alexandra and then of Queen Mary; finally it was set in the new Crown made by Garrard & Co. for the coronation of Her Majesty Queen Elizabeth the Queen Mother.

2 PITT OR REGENT

The splendid stone known successively as the Pitt and the Regent was discovered in 1701 at the famous diamond mines at Partial, on the Kistna, about 150 miles (240 km.) from Golconda in southern India, and weighed as much as 410 carats in the rough. By devious ways it came into the hands of Jamchund, a Parsee merchant, from whom it was purchased by William Pitt, Governor of Fort St George, Madras, for £20,400. On his return to England Pitt had it cut into a perfect brilliant (fig. 113), weighing 136⅞ carats (140·5 metric carats), the operation taking two years and costing £5000. More than £7000 is said to have been realized from the sale of the fragments left over. Pitt had an uneasy time, and lived in constant dread of theft of the stone, until in 1717 after lengthy negotiations he parted with it to the Duc d'Orleans, Regent of France, for the immense sum of 3,750,000 francs, then worth about £135,000. With the remainder of the French regalia it was stolen from the Garde Meuble on 17 August 1792, in the early days of the French Revolution, but was eventually restored by the thieves, doubtless because of the impossibility of disposing of such a magnificent stone, at least intact, and it is now exhibited in the National Collections at the Louvre at Paris. It measures about 30 mm. in length, 25 in width and 19 in depth (about 1⅛ by 1 by ¾ inches).



1 2

FIG. 113.—Pitt, or Regent, diamond: (1) crown, (2) side.

3 ORLOV

The famous Orlov stone has had the alternative names Amsterdam or Lasarev. It was believed by the Russian mineralogist, A. E. Fersman, to be the same stone as the one originally known as the Great Mogul and later as Derya-i-nur (River of Light). Probably the finest of the diamonds ever mined in India, it was discovered in the Killur mines of Golconda at the beginning of the seventeenth century. In its original condition it was a large portion, weighing about 300 carats, of a rounded dodecahedron which had been separated from the complete crystal by cleavage before it was found; if the crystal had been fully developed, it would have weighed about 450 carats, and the piece that was discovered was therefore about two thirds of the original mass. It was acquired by Shah Jahan, who had it cut in the form of a high rose with a large number of small facets arranged in tiers. The stone still retains its original Indian cutting, and is therefore of exceptional historical interest.

The base of the stone as cut is the cleavage face, and when placed on the base it measures in height 22, in length 35 and in width 31 to 32 mm. (about $\frac{7}{8}$ by $1\frac{3}{8}$ by $1\frac{1}{4}$ inches) respectively. The weight after cutting was reduced to 199·6 metric carats, and Shah Jahan was gravely dissatisfied with the loss in size that had ensued. The stone has an agreeable bluish-green tinge.

Upon the death of Shah Jahan the stone came into the possession of his son, Aurangzeb, and was seen in this potentate's treasure-house at Delhi by the French traveller, Tavernier, when he visited India in 1665; the stone was then known as the Great Mogul. Aurangzeb acquired also another large diamond, which may have been the Koh-i-nur. When Nadir Shah captured Delhi in 1739, among other loot he seized these two stones and embellished his throne with them.

There is a legend that the Orlov stone was one of the diamonds that served as the eyes of the statue of Brahma which was in a temple on an island in the Cauvery River, near Trichinopoli, in Madras, and was stolen at the beginning of the eighteenth century by a French soldier, who as a renegade had ingratiated himself with the temple priests and got appointed one of the guardians of the temple. He sold it for £2000 to the captain of an English ship, who in turn sold it to a Jewish dealer in London for £12,000.

Whatever may be the truth about the early history of this famous stone, there is no doubt that in 1773 it was bought by Prince Gregori Gregorievich Orlov from an Armenian merchant, Lasarev, at

Amsterdam, and presented by him to the Empress Catherine II of Russia. The sum paid is said to have been 400,000 roubles, or according to another version, £90,000, together with an annuity of £4000.

The Orlov stone was set in a silver chasing in the top of the Russian imperial sceptre, and it is now housed in the Diamond Treasury of the Union of Soviet Socialist Republics at Moscow.

4 SANCY

The history of the Sancy stone is very involved, and probably in the various stories two or more stones have been confused. It is described as almond-shaped and covered with tiny facets on both sides, and may have been the one bought at Constantinople about 1570 by Nicholas Harlai, Seigneur de Sancy, who was then French Ambassador to the Ottoman Court. Towards the end of the century, when Ambassador to the Court of St James's, he sold it to Queen Elizabeth. About a hundred years later, in 1695, the stone was sold by James II to Louis XIV of France for, it is said, 625,000 francs (about £25,000). It appears in the inventory of the French regalia made in 1791, when it was valued at 1,000,000 francs (about £40,000), but was stolen from the Garde Meuble on 17 August 179. In the inventory it was stated to weigh $53\frac{3}{4}$ carats (55 metric carats).

It has been suggested that it was the stone belonging to Charles the Bold and snatched from his dead body on the fatal field of Nancy in 1477 by a marauding soldier, but there is no evidence to confirm this story and it cannot be accepted. The stone was next heard of in 1828, when it was sold to Prince Demidoff. It was shown at the Paris Exhibition in 1867, and was eventually bought by the late Lord Astor. At the present time it is in the possession of Lady Astor.

Confusion with another stone probably accounts for the statement that the Sancy was sold to an Indian purchaser towards the end of the nineteenth century and passed into the possession of the Maharajah of Patiala.

5 SHAH

The fine stone known as the Shah, which is not of the purest water, having a faint yellowish tinge due to a little iron oxide near the surface, was found at the Golconda mines in the sixteenth century, probably towards its close. The shape of the stone is an elongated octahedron, in which the eight original faces have been partially replaced by fifteen facets. A groove has been cut round the stone to accommodate the thread by which it was formerly worn round the neck.

The stone is said to have originally weighed 95 carats and to have suffered the small loss of 9 carats in cutting; its weight to-day is 88·7 metric carats. The most remarkable feature of this stone is that on three of the original faces the names of three of the rulers who in succession owned it and the corresponding dates are inscribed in Persian script of the Hijra era. If we remember the difficulty of cutting diamond and the primitive tools which were then available, we must stand amazed at the immense labour and incredible patience that the inscriptions demanded. The names, in English, of the three rulers and the dates are: Nizam Shah 1000 (A.D. 1591); Jahan Shah 1051 (A.D. 1641); Fath Ali Shah 1242 (A.D. 1826). It passed by conquest from Indian to Persian hands, and finally in 1829 it was conveyed by the son of the Shah to the Russian Court in compensation for the murder of a Russian envoy. It is now stored in the Diamond Treasury of the Union of Soviet Socialist Republics at Moscow. A second diamond inscribed in Persian script is mentioned on p. 237.

6 AKBAR SHAH

Once the property of the Mogul Emperor, Akbar, the diamond called after him was engraved on two facets with Arabic inscriptions by order of his successor, Jahan. The English translation of them is 'Shah Akbar, the Shah of the World, 1028', and 'To the Lord of two Worlds, Shah Jahan, 1039'. The dates, which are in the Hijra era, correspond to A.D. 1618 and 1629.

The stone disappeared, but eventually turned up in Turkey under the name 'Shepherd's Stone'. It was recognized, because it still bore the original inscriptions, which unfortunately were destroyed when the stone was cut into drop-form in 1866. In the following year the diamond passed into the possession of the Gaekwar of Baroda for, it is said, 3½ lacs of rupees (about £26,000).

The weight of the stone was originally 120 Arabic carats (about 119 metric carats), and was reduced to about 74 metric carats after the stone was cut.

7 NASSAK

The Nassak diamond is called after the tower of that name, now spelt Nasik, which is just under 100 miles (160 km.) north-east of Bombay. It was among the treasures of the neighbouring temples, and was seized by the Mahrattas, when they overran the country. Ultimately after the war in 1818 it was part of the Deccan booty which fell into the hands of the East India Company, by whom it was sold to the London jewellers, Rundell and Bridge. Originally it had an irregular pear shape, but was then skilfully recut into a beautiful triangular brilliant, and at an auction in August 1837 was bought by the then Marquess of Westminster. It was eventually acquired by Georges Mauboussin of Paris, and later by H. Winston of New York, by whom it was recut. The present owner is Mrs W. B. Leeds of New York.

The original weight was said to have been 89¾ English carats, which was reduced by cutting to 78¼ English carats (80·3 metric carats). The present weight, after re-cutting, is 43·3 carats.

8 TAJ-E-MAH

The stone known as Taj-e-mah (Crown of the Moon) came no doubt from the Golconda mines. It was Indian cut in rose form and was of the purest water. It was among the loot captured by Nadir Shah in 1739, and is believed to be still among the Persian treasures. The weight is given as 146 carats.

9 PIGOTT

The fine stone known as the Pigott was somehow acquired by Lord Pigott, who was twice Governor of Madras in the stirring days of Clive and Warren Hastings; he died at Madras in 1776. He is supposed to have brought the diamond to England in 1775, and to have sold it. In 1818 it was bought by Ali Pasha, Viceroy of Egypt, for £30,000, and was destroyed by his orders at his death.

Statements of the weight of the Pigott diamond vary very considerably. A probable estimate is about 49 carats.

10 EUGÉNIE

The beautiful oval-shaped brilliant called the Eugénie was first heard of as the property of Catherine II of Russia. She gave it to Potemkin, one of her favourites, in recognition of his military services. From his family it was acquired by Napoleon III as a bridal gift to the Empress Eugénie. She wore it as the centre stone of a diamond necklace. Upon the Emperor's downfall it was sold to the Gaekwar of Baroda for, it is said, a lac and a half of rupees (about £11,000).

The weight is given as 51 carats.

11 HOPE

The largest of coloured diamonds, the Hope, weighs 44·4 metric carats, and is of a deep sapphire-blue in colour. It is believed to be the main portion of a drop-form stone (d'un beau violet), which was found at the Kollur mines, Golconda, and was secured by Tavernier on his visit to India in 1642 and sold by him to Louis XIV in 1668; it then weighed 67 carats. This stone was stolen with the remainder of the French regalia from the Garde Meuble on 17 August 1792, but was never recovered. In 1830 the present stone (fig. 114) was offered for sale by Eliason, a London dealer, and was purchased for £18,000 by Henry Philip Hope, a wealthy banker and a keen collector of gemstones. It is described and illustrated in the catalogue of the collection.[1]

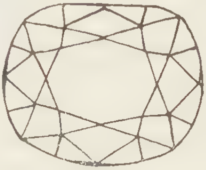


FIG. 114.—Hope diamond.

Blue diamonds are so rare that it is plausible to suppose that the apex of the original drop-form stone was cut off and the large piece re-cut into the brilliant form. The slight want of symmetry of the present stone lends confirmation to this view, and two other blue stones are known,

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[1] 'No. 1. A most magnificent and rare brilliant, of a deep sapphire blue, of the greatest purity, and most beautifully cut; it is of true proportions, not too thick, nor too spread. This matchless gem combines the beautiful colour of the sapphire with the prismatic fire and brilliancy of the diamond, and, on account of its extraordinary colour, great size, and other fine qualities, it certainly may be called unique; as we may presume that there exists no cabinet, nor any collection of crown jewels in the world, which can boast of the possession of so curious and fine a gem as the one we are now describing; and we expect to be borne out in our opinion by our readers, since there are extant historical records and treatises on the precious gems, which give us descriptions of all the extraordinary diamonds in the possession of all the crowned heads of Europe, as well as of the princes of Eastern countries. But in vain do we search for any record of a gem which can, in point of curiosity, beauty, and perfection, be compared with this blue brilliant.

'Diamonds are found of almost every colour, which is proved by the great variety of coloured diamonds in this collection; but the blue colour is the most rare and most valuable, since there has very seldom been found a diamond of any size of a fine deep sapphire blue, those which are termed blue diamonds being generally of a very light or of a steel-blue colour: it would, therefore, be a difficult task to form a just estimate of the value of this unrivalled gem, there being no precedent, the value cannot be established by comparison. The price which was once asked for this diamond was 30,000 *l.*, but we must confess, for the above-stated reasons, that it might have been estimated at a higher sum. To convey to the reader by a description a just conception of the beauty and splendour of this unique production of nature would be a vain attempt.

'This beautiful gem is most tastefully mounted as a medallion, with a border *en arabesque* of small rose diamonds, surrounded by 20 brilliants of equal size, shape, and cutting, and of the finest water, and averaging four grains each. Its weight is 177 grains.' B. Hertz, *A Catalogue of the Collection of Pearls and Precious Stones formed by Henry Philip Hope, Esq.*, London, August 1839, p. 25.

The diamond is figured on plate 5 of the catalogue, where, however, the weight is given as 176 grains. It may be noted that, since the weight of the diamond is equivalent to 137 grains, the brilliants could not have averaged more than two grains each.

which, together with the Hope, would make up the weight of the original stone, allowing for the loss in cutting. It appears to have remained in the possession of the Hope family until, in 1908, the owner disposed of it to Habib Bey. In the following year, 1909, it was bought by Rosenau, the Paris diamond merchant, at an auction in that city, and was sold by him in January 1911 to Mr Edward Maclean of Washington. In 1949 it was bought by H. Winston of New York, and in 1958 he presented it to the Smithsonian Institution in Washington.

The Hope diamond is supposed to bring ill-luck in its train, and its history has been liberally embellished with fable to establish the myth.

12 AUSTRIAN YELLOW, TUSCANY OR FLORENTINE

The early history of the diamond, known as the Austrian Yellow, the Tuscany or the Florentine, is uncertain, but there can be no doubt that it was the one seen by Tavernier among the treasures in the possession of the Duke of Tuscany and described by him as weighing 139½ carats and having a colour running into a citron yellow. It passed into the possession of the Austrian Royal House, and was in the Hofburg at Vienna in 1938; its present location is unknown. It is cut into a nine-rayed briolette, and weighs 137·27 metric carats.

The weight recorded by Tavernier is not in close agreement with that of the diamond now at Vienna.

13 STAR OF ESTE

Although a comparatively small stone, the alleged weight being only 25½ carats, the Star of Este is noted for its perfection of form and quality. It belonged to the Grand Duke Franz Ferdinand of Austria-Este. After his assassination it presumably reverted to the Emperor, and was said to have been in the possession of Emperor Charles, who died in exile in 1922. Its later history is unknown.

14 POLAR STAR

The beautiful diamond known as the Polar Star is said to weigh about 40 carats. It passed into Russian possession, and is now owned by Lady Deterding.

15 NIZAM

The Nizam of Hyderabad possesses a large stone known as the Nizam, weighing 340 carats, which was broken at the beginning of the Indian Mutiny. It is reported to have been used as a paperweight. Models show a very primitive type of cutting, with grooves and a few facets.

16 DRESDEN WHITE

Square in contour and said to weigh $48\frac{3}{4}$ carats, the beautiful white diamond, set in a shoulder knot, which was in the famous Green Vaults at Dresden, was bought by Augustus the Strong for 1,000,000 thalers (about £150,000). The jewels in the Vaults are reported to have been safely preserved during the second world war and to have passed subsequently into the possession of the U.S.S.R.

17 DRESDEN GREEN

A beautiful apple-green diamond, faultless and of the purest water, set in a hat ornament, was also in the Green Vaults at Dresden. It weighs 41 metric carats. It was bought by Augustus the Strong in 1743 for 60,000 thalers (about £9000).

18 DRESDEN YELLOW

Among the treasures in the Green Vaults at Dresden were four beautiful yellow diamonds cut as brilliants. The largest of them weighs about 38 metric carats.

19 PAUL I

A diamond, weighing 10 carats, known as Paul I, was among the old Russian regalia. This stone has been described in the past as being 'fine ruby-red', but the Russian mineralogist, A. E. Fersman, stated that the stone itself was a delicate pinkish water and owed its ruby colour to a backing of foil and to colouring of the stone on the reverse side.

20 CUMBERLAND

A fine diamond, which was said to weigh 32 carats, was purchased by the City of London for £10,000 and presented to the Duke of Cumberland in appreciation of his victory at Culloden in 1746.

21 PASHA OF EGYPT

The 40-carat brilliant known as the Pasha of Egypt was originally bought by Ibrahim, Viceroy of Egypt, for £28,000. It was the finest stone among the Egyptian treasures.

22 MISCELLANEOUS

An apparently hitherto unrecorded diamond of 83·05 carats, formerly the property of the Maharajah of Burdwan, which was sold at Christie's in London in 1954 for £13,000, is of special interest because, like the

Shah diamond (p. 233), it is inscribed in Persian characters, bearing on one facet the names of two of the Mogul Emperors. It was re-sold at Sotheby's in 1957 to Mr C. Patel for £14,000.

In the account [1] of his travels in the East Tavernier describes several large diamonds which cannot now be readily identified with any known stones.

The Great Mogul diamond, which he saw at the Court of Aurangzeb in 1665, was said to be a huge, rose-cut stone, weighing $319\frac{1}{2}$ ratis, equivalent to 280 French carats. It was reported to have weighed 900 ratis or $787\frac{1}{2}$ French carats in the rough. Its later history is unknown, but amongst the loot taken from Delhi in 1739 by Nadir Shah was a large rose-cut diamond called Derya-i-nur (River of Light), and it has been held that this was the Great Mogul and was the same stone as the one now known as the Orlov. The recorded weights do not agree, but little reliance can be placed upon the weights of stones recorded so long ago when the value of the unit used is a matter for speculation. Against this identification, however, Derya-i-nur is reputed to have been seen by Sir John Malcolm in the Persian Crown Jewels in 1827.

An unmounted brilliant-cut diamond, weighing 183 carats, was sold in London under the name of the Moon in 1942; it was alleged to have been once among the Russian Crown Jewels, and then to have been known as the Moon of the Mountains.

Among the large diamonds which Tavernier saw at Golconda in 1642 was a large tabular stone which weighed $176\frac{1}{8}$ mangelins or $242\frac{5}{16}$ French carats, the mangelin, a unit in use in Golconda and Visapur, being equivalent to $1\frac{3}{8}$ French carats. (It has recently been suggested, however, that the Great Table, as this stone has been called, was in fact not a diamond but a ruby, examples of which are described by Tavernier in the same chapter.)

In addition to the named diamonds already described the old Russian regalia contains the following five diamonds, all of which are probably Indian in origin: the octagonal stone of about 57 metric carats in weight, which is in the great crown of the Empress Catherine II; the stone of 46 metric carats in weight, bluish in tint and a high rose-cut in shape, which is set in the Imperial Orb; the broad briolette, of clear water and weighing 40·5 metric carats, which is set in a pin; a flat stone, weighing about 24 metric carats and measuring on its flat face 7·5 sq. cm. and 0·25 cm. in thickness, which is mounted in a gothic gold

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[1] *Les six Voyages de Jean-Baptiste Tavernier qu'il a faits en Turquie, en Perse et aux Indes, pendant l'espace de quarante ans, etc.*, Paris 1676 and 1682.

setting [1]; and a large single stone, weighing about 54·7 metric carats. All these stones are in the Diamond Treasury at Moscow.

ii *BRAZIL*

I STAR OF THE SOUTH

The largest of the Brazilian diamonds, to which the name Star of the South has been given, was discovered at the mines of Bagagem in Minas Gerais in July 1853. (Until about twenty years ago the spelling of this well-known mineral locality on most maps was Minas Geraes.) Perfectly transparent and without tint, it was originally a rhombic dodecahedron with curved faces and weighed 261·88 metric carats; it was sold for £40,000. The stone was cut at Amsterdam as a perfect brilliant, the weight being reduced to 128·8 metric carats; it was bought by the Gaekwar of Baroda.

2 ENGLISH DRESDEN

The beautiful stone known as the English Dresden was found at the Bagagem mines in Minas Gerais about the same time as the Star of the South. It was a part separated by cleavage from a larger mass, and in the rough weighed 119½ carats. Mr E. Dresden, who acquired it and after whom it was named, had it cut into a drop-form brilliant, weighing 76½ carats. Ultimately it was bought by the Gaekwar of Baroda.

3 STAR OF EGYPT

Until its appearance on the London market early in 1939 the magnificent Brazilian diamond, to which the name Star of Egypt has been given, was utterly unknown. It is said to have been discovered about the middle of last century, and to have been acquired by the Khedive of Egypt. At the time it weighed about 250 (old) carats, and was oval in shape. He sold it in 1880 or about that time, and it was then re-fashioned into an emerald-cut brilliant form, the weight being reduced to 106·75 metric carats. The stone is a hard dead white in colour, and owing to the perfection of its shape, its fire is extraordinarily lively.

4 STAR OF MINAS

A large diamond was found at the Bagagem mines in Minas Gerais in 1911, and was called Estrella de Minas (Star of Minas). It was bounded by two plane faces and the remainder of the surface was rounded; its weight was 179·3 metric carats.

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[1] This diamond appears to have been known as the Table at the Russian Court; it must not be confused with Tavernier's Table, which has disappeared.

5 MINAS GERAIS

A big diamond, weighing 172·5 metric carats, was found in the alluvial deposits of the Rio Santo Antonio, Coromandel municipality, Minas Gerais, not long before the discovery of the much larger stone, next to be described, and was named after the State.

6 PRESIDENTE VARGAS

The splendid diamond, which was discovered in the alluvial deposits of the Rio Santo Antonio, Coromandel municipality, Minas Gerais, on 13 August 1938, and was named after Dr Getulio Dornelles Vargas, President of the United States of Brazil, weighs 726·6 metric carats and is of the purest water, except for a faint yellowish tinge on two of its edges. Somewhat flattened in shape, it shows two faces of the rhombic dodecahedron and a large cleavage face, and in extreme dimensions measures 56·2 by 51·0 by 24·4 mm. (2¼ by 2 by 1 inches). In the ultra-violet rays it displays a beautiful bluish-violet fluorescence.

7 MISCELLANEOUS

A diamond weighing 118 carats was reported to have been found in the Abacte River, Minas Gerais, in June 1929. It was named 'Southern Cross'.

The Braganza stone, which was found in Brazil about 1740 and was said to weigh as much as 1680 carats, is in the Portuguese regalia; it is probably a topaz. Another Brazilian stone, the Regent of Portugal, which was discovered in 1775(?) and was cut into a circular brilliant of 215 carats, is probably also a topaz.

iii *SOUTH AFRICA*

1 CULLINAN

All diamonds pale into insignificance when compared with the colossal stone which came to light at the Premier mine, near Pretoria in the Transvaal, on 25 January 1905. It was named after Sir Thomas Cullinan, Chairman of the Premier Diamond Mine (Transvaal) Company. The rough stone weighed 3106 metric carats (621·2 grams, slightly over $1\frac{1}{3}$ lb.),[1] and displayed three natural faces (plate XVI), its shape suggested

[1] Sir William Crookes, F.R.S. (1832–1919), in his British Association lecture at Kimberley gave the weight as 9586·5 grains, which is almost exactly equivalent to 621·2 grams, *Chemical News*, 1905, vol. 92, p. 139. L. J. Spencer has brought together the various weights published, *Mineralogical Magazine*, 1910, vol. XV, pp. 318–26.

1. Alexandrite (in daylight). 2. Amethyst. 3. Alexandrite (in artificial light). 4. Topaz crystal. 5. Tourmaline crystal (in matrix). 6. Smoky quartz. 7. Cat's-eye (chrysoberyl). 8. Tourmaline crystal (in section). 9. Citrine. 10. 'Hope' chrysoberyl. 11. Tiger's-eye. 12. Opal (in matrix). 13. Quartz cat's-eye

XVII. GEMSTONES

that it was a portion of a much more enormous stone more than double its size. It was transparent and colourless, and had only one small flaw near the surface. This magnificent diamond was purchased by the Transvaal Government for £150,000 and presented to King Edward VII on his birthday, 9 November 1907.

The Cullinan was entrusted to the firm of I. J. Asscher & Co., Amsterdam, for cutting on 23 January 1908, just three years after its discovery. On 10 February it was cleaved into two parts, weighing respectively 2029·94 and 1068·09 metric carats, from which the two largest stones were cut. The first, to which the name of Star of Africa was given by King George V, is a pendeloque or drop brilliant in shape (fig. 115), weighs 530·2 metric carats, is cut with 74 facets and is the largest cut diamond in the world; it has been set in the head of the Sovereign's Sceptre. The second is a square brilliant (fig. 116), weighing 317·4 metric carats and cut with 66 facets; it is set in the Imperial State Crown. Two other large stones, the one a pendeloque brilliant, weighing 94·45 metric carats, and the other a square brilliant, weighing 63·65 metric carats, were set in the late Queen Mary's Crown for her coronation in 1911 and were shown set in a brooch at an Exhibition, 'The Ageless Diamond', in London in 1959. The stones Cullinan II, III and IV have been called Lesser Stars of Africa. Besides these four large stones there were a heart-shaped stone, 18·85; two marquises, 11·51 and 8·8; an oblong stone, 6·8; a pendeloque, 4·4; and 96 small brilliants, weighing

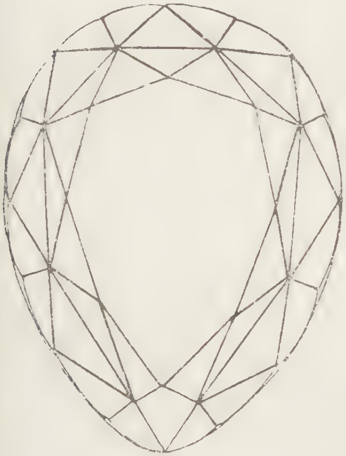

FIG. 115.—Cullinan I or Star of Africa.

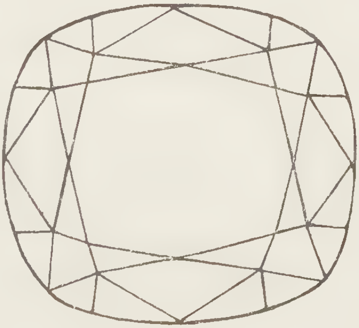

FIG. 116.—Cullinan II.

together 7·55 metric carats. The total weight of the cut stones is 1063·65 metric carats, representing a loss in cutting of 65·75 per cent. The work was completed and the stones passed into the possession of King Edward VII in November 1908.

2 EXCELSIOR

On 30 June 1893 there was found in the Jagersfontein mine a diamond, which until the discovery of the Cullinan was by far the largest of the South African stones. It was given the name Excelsior. The stone was irregular in shape, with a cleavage face on one side, excellent in quality and bluish-white in tint. In the rough it weighed 995·2 metric carats (about 7 oz.). It was cut by I. J. Asscher & Co., Amsterdam, in 1904, and yielded twenty-one brilliants, the largest weighing respectively 69·68, 47·03, 46·90, 40·23, 34·91, 28·61, 26·30, 24·31, 16·78, 13·86 and 9·82 metric carats; the cut stones weighed altogether 373·75 metric carats, representing a loss in weight of 62·44 per cent. The stones were sold separately.

3 JUBILEE OR REITZ

At the end of 1895 there was found in the Jagersfontein mine a large diamond, to which at first the name Reitz was given in honour of Mr F. W. Reitz, who was then President of the Orange Free State. In 1897, however, when the stone had been cut, its name was changed to Jubilee, to commemorate the sixtieth anniversary of Queen Victoria's accession to the throne.

As found, the diamond was in form an irregular octahedron without definite faces and weighed 650·8 metric carats. A splendid, faultless, brilliant, weighing 245·35 metric carats, was cut from it, and from the material remaining over a pendeloque brilliant, weighing 13·34 metric carats, was obtained. The large brilliant was shown at the Paris Exhibition of 1900. Its present location is uncertain.

4 IMPERIAL, VICTORIA OR GREAT WHITE

In 1884 a large diamond, to which no fewer than three alternative names have been given, made a surreptitious appearance on the London market, having in all probability been smuggled from the Cape. From its characters the stone had come from the Jagersfontein mine. Its original weight in the rough was 457 carats (469 metric carats). When it was cut in Amsterdam two stones were obtained, of which the larger, an oval brilliant, weighed 180 carats (185 metric carats), and the smaller, a circular brilliant, weighed 19⅝ carats (20 metric carats). The former was sold to the Nizam of Hyderabad for £20,000.

5 DU TOIT

Two large diamonds are called Du Toit after the mine, Dutoitspan, at Kimberley, in which they were found. The larger, I, was mined in 1878 and weighed 244 carats (250 metric carats). The smaller, II, was discovered much earlier, in 1871, and weighed 124 carats (127 metric carats). Both were yellowish in tinge.

6 PORTER-RHODES

On 12 February 1880 a blue-white octahedron was found in the claim of Mr Porter-Rhodes, after whom the diamond was named, at the Kimberley mine. It weighed 150 carats (153·5 metric carats), and was the most remarkable stone, not only for its size but also for its quality, which up to that date had been discovered in South Africa. In 1937 it passed into private ownership in India.

7 STEWART

In 1872 the largest diamond which had up to that date been discovered in South Africa was found at the Vaal River diggings; it is said to have been ultimately sold for £9000. It weighed 288⅜ carats (296 metric carats), but like so many South African stones had a faint yellowish tinge. From it a brilliant, weighing 128 metric carats, was cut.

8 DE BEERS

In 1888 a pale-yellowish octahedron, with curved faces, weighing 428½ carats (440 metric carats), was found in the De Beers mine and called by its name. From it was cut a brilliant, weighing 234·5 metric carats, which was bought by an Indian Prince.

9 STAR OF SOUTH AFRICA OR DUDLEY

The first diamond of considerable size produced by South Africa came from the Vaal River diggings. It was found by a native, from whom it was acquired in 1869 by Mr S. Van Niekirk, who is said to have sold it for £11,200. Its quality was excellent, and its weight in the rough was 83½ carats. It was cut into a pear-shaped brilliant, weighing 47·7 metric carats, and was purchased by the Countess of Dudley, after whom it is alternatively named.

10 TENNANT

In the early days of the South Africa mines, in 1873, a considerable diamond came into the possession of James Tennant, the well-known mineral dealer in London (p. 252), after whom it was named. Of a yellowish tinge, it weighed in the rough state 112 carats, and, when cut as a flawless brilliant, was reduced to 66 carats (68 metric carats).

11 TIFFANY YELLOW

The beautiful orange brilliant, weighing 128·7 metric carats, which is in the possession of Tiffany & Co., the jewellers of New York, after whom it is named, was discovered in the Kimberley mine about 1878. It has long been on display to the public in the Tiffany store in New York.

12 JAGERSFONTEIN OR PAM

Three large diamonds are known from the Jagersfontein mine. The largest, called the Julius Pam, was found in 1889 and weighed 248 metric carats in the rough and 123 metric carats when cut. The second was found in 1881 and called the Jagersfontein; its weight in the rough was 215 metric carats. The date of the third, called the Pam, is uncertain, but it was before 1891; it weighed in the rough 115 metric carats, and, when cut, 56·5 metric carats.

13 RED CROSS

A large, canary-yellow, square-shaped brilliant was given by the Diamond Syndicate of London to the art sale in April 1918 in aid of the funds of the British Red Cross Society and the Order of St John of Jerusalem, to which fact it owes its name.

The stone was found in the De Beers Company's mines, Griqualand West, and originally weighed between 370 and 380 metric carats. After cutting it weighed 205 metric carats. A remarkable feature of the stone is that through the table facet a series of inclusions are visible, arranged in the form of a maltese cross.

14 TIGER-EYE

In October 1913 a deep amber-tinted diamond, to which the name Tiger-eye was given by the discoverers, was found at Droogefeld, Vaal River. It weighed 178½ carats in the rough and 61½ carats when cut in Amsterdam as a brilliant.

15 JONKER

In January 1934 a large diamond was found in the claim belonging to Jacobus Jonker, after whom it was named, in the alluvial deposits at Elandsfontein, near Pretoria, about three miles from the Premier mine. It had a cleavage face but otherwise was rounded in shape, and was about as big as a hen's egg, measuring $2\frac{1}{2}$ inches in length by $1\frac{1}{2}$ inches across (63 by 38 mm.). Flawless and of the coveted blue-white class, it weighed 726 metric carats (about 5 oz.). The Diamond Corporation acquired the stone for about £70,000, and disposed of it in America. The largest stone cut from it, 125 carats, is in the possession of the Egyptian Government.

16 COLENSO

A beautiful yellowish octahedral crystal of diamond is exhibited in the Mineral Department of the British Museum (Natural History) at South Kensington. It was presented to the Trustees in 1887 by John Ruskin, who all his life took a keen interest in gemstones, particularly from the aesthetic standpoint, and was named by him 'In Honour of his Friend, the loyal and patiently adamantine First Bishop of Natal'. John William Colenso (1814–83), a distinguished mathematician and known to many generations of students for his treatises on arithmetic (1843) and algebra (1841), especially the former, was Bishop of Natal from 1853 until his death in 1883. His critical review of the Pentateuch books of the Old Testament aroused a bitter controversy which he bore with sweet patience.

The crystal is a nearly perfect octahedron, the faces of which show the characteristic markings, and weighs 133·145 metric carats (nearly 1 oz.).

17 CUBAN CAPITOL

A yellow diamond, weighing 23 carats, was purchased in Paris in 1928 for the sum of £8000, which was raised by subscription among the workers at that time engaged in building the Cuban Capitol at Havana. Set in platinum and gold, it was embedded in the marble floor of the vestibule that separates the Senate and House of Representatives, immediately beneath the centre of an inlaid eight-pointed star, representing the points of the compass. It was used as the origin from which distances were measured on the highways in Cuba. The diamond was stolen on 25 March 1946. Although not definitely stated, it was no doubt a South African stone.

18 MISCELLANEOUS

Besides the large stones which have been mentioned, the South African mines have supplied a host of others, all of which are nameless and have no after-history. The market for faceted diamonds of considerable size must be very restricted, and it was probably thought wise in every instance to cut the piece into stones of more marketable sizes. In his book [1] Alpheus F. Williams gives a long list, with dates, of stones found that were at least 100 carats in weight. It suffices here to say that the list includes sixteen which were between 400 and 500 carats and fourteen which exceeded 500 carats.

iv *MINOR COUNTRIES*

Diamond deposits have been known in Borneo since the early eighteenth century, and there is a story that a diamond weighing 367 carats was discovered in the Landak mines near the west coast in 1787. The truth of the story is open to grave doubt because no one competent to judge has had the opportunity of examining the stone; it probably is only a piece of quartz. The Mattan stone belonged to the Raja of Mattan, after whom it was named.

In 1944 a large diamond, weighing 155 carats, was found in Venezuela, and was named the Libertador (Liberator). It was cut in New York to form three stones, weighing 40, 18·12 and 8·92 carats respectively.

B. OTHER STONES

Unlike diamonds, the number of examples of the other precious stones which have been honoured with names and have passed into history is small. The reason may be the enormously greater hardness of diamond, which has always set it in a position in general esteem far above the other species, once its existence had become known.

I BLACK PRINCE'S RUBY

The famous red stone known as the Black Prince's Ruby, which is one of the greatest treasures among the British Crown Jewels, is second to none in the romance of its history. Where it was found is not known. The first mention of it is in 1367, when it formed part of the treasure of the King of Granada, which was seized by Dom Pedro, King of Castile, by the expedient, which was not uncommon in days when might was right, of first of all depriving the unfortunate owner of his life. Dom Pedro received valuable military assistance from the Black Prince, the gallant son of Edward III, at the battle of Nagera, near Vitoria in northern Spain. Henry V wore the stone in his coroneted helmet on the victorious day of Agincourt, when he owed his life to the helmet, which deflected the nearly fatal blow struck by the Duc

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[1] *The Genesis of the Diamond*, London, Ernest Benn Limited, 1932, pp. 619–35.

d'Alençon. Fortunately the Ruby escaped without damage. By order of the Commonwealth all the Crown Jewels unhappily were ordered to be sold. Among them was the Black Prince's Ruby, which in the inventory was valued at £4 only; with every allowance made for the much greater purchasing power of money in those times as compared with that of to-day, the valuation is absurdly low. What became of the stone is not known, but it may credibly be supposed that some well-wisher of the monarchy bought it at the sale and surrendered it when once more a king ruled in the land; for in the original setting of Charles II's crown, which still exists, there is a position which from its peculiar shape could only have been provided for the Black Prince's Ruby.

The Black Prince's Ruby still occupies the most conspicuous position in the Imperial State Crown, in the centre of the front cross-patée. No attempt has ever been made to fashion the stone, the surface having merely been polished. Its shape is therefore irregular, the length being nearly 2 inches (5 cm.). It was pierced at one end, to enable it to be worn as a pendant, but the hole is now filled by a small ruby.

This marvellous jewel was called a ruby in days when red stones were indiscriminately grouped under this name. It was, however, recognized as a spinel, 'large ballas ruby', in the inventory of the Crown Jewels prepared by order of the Commonwealth. Red spinel ranks below the true ruby, but in the instance of the Black Prince's Ruby what the species may be is in truth immaterial, since the value lies in its romantic history and its long connexion with the British Crown. Even to hazard a guess as to its value is, indeed, an impossibility.

2 TIMUR RUBY

Among the British Crown Jewels is the splendid red spinel, which under the name of Khiraj-i-Alam (Tribute of the World) has been famous throughout the East for nearly 600 years, and in the West is known as the Timur Ruby. Together with three smaller but similar spinels, some pearls and an emerald girdle, it was presented to Queen Victoria in 1851 by the Directors of the East India Company. It is believed to be by far the largest red spinel known to exist, and is said to weigh 352 carats (361 metric carats); the weights of the other three stones are given as 94 (96), 72 (74) and 34 (35) carats respectively, the equivalent in the metric unit being in brackets. The Timur Ruby was mounted with the two larger stones on either side in a necklace composed of clusters and trident-shaped links set with diamonds, the smallest spinel being placed in the snap. The necklace remains much as it was then, and has been altered only to the extent that the diamond drops which were formerly attached to it are now otherwise used; normally it is placed in the Indian Room at Buckingham Palace. Happily all these spinels were allowed to remain in their original Indian form, and the Timur Ruby still retains its inscriptions. By these it was identified,[1] for it had long been supposed to have been lost. Since the Timur Ruby is not faceted, comparatively little light is reflected from the interior, and its colour therefore appears rather dark.

The largest of the inscriptions is in Persian, but is written in the Arabic script. The following is a literal translation in English: 'This (is) the ruby from the twenty-five thousand genuine jewels of the King of Kings the Sultan Sahib Qiran which in the year 1153 (A.D. 1740) from (the collection of) jewels of Hindustan reached this place (Isfahan).' The remaining five inscriptions, which are also in Persian, but are written in the Persian script as well, are the names of some of the Emperors who had it in their possession, and the corresponding dates: Akbar Shah Jahangir Shah, 1021 (A.D. 1612); Sahib Qiran Sani, 1038 (A.D. 1628); Alamgir Shah, 1070 (A.D. 1659); Badshah Ghazi Mahamad Farukh Siyar, 1125 (A.D. 1713); Ahmad Shah Durr-i-Dauran, 1168 (A.D. 1754). The original dates are those of the Hijra era. The stone formerly bore the names of three earlier owners, but these were removed by Jahangir or one of his successors.

From these inscriptions it is evident that this spinel is the famous stone which fell into the hands of the renowned Tartar conqueror, Timur, or Timur-i-Leng (The lame Timur), who was known to Europeans usually as Tamerlane, but to the Moslem world as Sahib Qiran (Lord of the auspicious conjunction), when he captured Delhi in 1398. He appears to have taken it back with him to Samarkand on his return to Persia. Timur was born in 1336, and during his remarkable career carried his victorious arms from the Persian Gulf to the Volga and from the Ganges to the Hellespont. He was planning an incursion into China when he died in 1405.

Timur was succeeded by his fourth son, Mir Shah Rukh, whose name is one of those formerly inscribed on the stone. The latter was succeeded in 1447 by his son, Mirza Ulugh Beg, famous as an astronomer, whose name also appeared on it. He was murdered by his son in 1449. Upon the wane of the Timur dynasty the power passed to the Safavi family. The ablest member of it was Shah Abbas Safavi, who reigned from 1587 to 1629; his name was also at one time engraved on the stone.

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[1] 'Engraved spinel rubies.' India Office paper by Lieut.-Col. Sir James R. Dunlop Smith, 21 March 1912.

The Timur Ruby was presented by Shah Abbas Safavi to the Mogul Emperor, Jahangir, who inscribed on it in 1612 his own name and that of his father, the great Akbar, and probably had the earlier inscriptions removed. Jellaladin Mohammed Akbar, who was born in 1542, succeeded in 1556, and died in 1602, was the greatest and the wisest of the Mogul Emperors. His son Jehangir, or Jahangir (Conqueror of the World), was born in 1569 and died in 1627. He was succeeded by Shah Jahan, who will always be remembered for that architectural marvel at Agra, the Taj Mahal, which he built as a mausoleum for his favourite wife, Mumtaz Mahal, and where he himself now lies. It was he who erected in the Diwan-i-Am (Hall of Public Audience) at Delhi the famous Peacock Throne, embellished with an immense number of precious jewels, among them the Timur Ruby. In recording his possession of the stone he designated himself as Sahib Qiran Sani (Second Lord of the auspicious conjunction); the first of that name was the great Timur, and the conjunction referred to was that of Venus and Jupiter. In 1658 he was deposed from his throne by his third son, Alamgir (Conqueror of the World) Shah, the name engraved on the stone, who was more commonly known by his earlier name, Aurangzeb (Ornament of the Throne). He died in 1707. Neither of the two Emperors, who successively reigned for a few years after him, had their names inscribed on the Timur Ruby, but the name of the Emperor Mahamad Farukh Siyar, who reigned from 1713 to 1718, is on it. By then the power of the Mogul Emperors had fallen to a low and almost vanishing point, and during the reign of Muhammad Shah, who succeeded in 1719, it suffered eclipse when the great Nadir Shah invaded India and captured Delhi in 1739. Amongst the enormous booty which he took with him to Persia, valued at from eight to thirty million pounds sterling, was the Timur Ruby, as the long inscription on it states. The booty also included the Koh-i-nur diamond, and the subsequent events which led to the jewels passing into the possession of Ranjit Singh at Lahore have been related on p. 229.

The Timur Ruby remained at Lahore until the annexation of the Punjab in 1849 after the Second Sikh War, when the whole of the State Jewels came into the possession of the East India Company. The jewels do not appear to have been critically examined, and the great diamond alone was recognized; it was sent by special messenger direct to Queen Victoria, but the remainder, including the Timur Ruby, were packed and dispatched to London by ordinary transport. All the jewels, including the great diamond, were shown at the Great Exhibition in 1851. The famous Timur Ruby was, however, not identified, and, together with the three red spinels with which it is still associated, appears anonymously in the *Official Catalogue* (p. 160) in the following entry: 'Short necklace of four very large spinelle rubies.' Thus in obscurity remained a gem with a long and romantic history until some sixty years later it was recognized by the inscriptions that it still bears.

It may be noted that ever since 1612 the Timur Ruby and the Koh-i-nur diamond have always belonged to the one owner, in spite of the many times that they have changed hands and their wanderings from India to Persia, thence to Afghanistan and on to the Punjab, and finally to England.

3 ST EDWARD'S SAPPHIRE

In the centre of the finial cross-patée of the Imperial State Crown is a fine sapphire, of good colour, which is probably the oldest stone in the regalia. It was rose-cut, probably in the seventeenth century. According to tradition in its original form it was mounted in the ring worn by Edward the Confessor, who ascended the throne in 1042.

4 STUART OR CHARLES II'S SAPPHIRE

At the back of the Imperial State Crown is another fine sapphire, which measures 1½ inches in length by 1 inch in breadth (3·8 by 2·5 cm.). It was used for the State Crown of Charles II, but was taken by James II on his flight to France in 1688. From him it passed to his son, James Edward, the old Pretender, and then to the latter's son, Henry Benedict, Cardinal York, who bequeathed it with the other Stuart treasures to George III.

At Queen Victoria's coronation the Stuart Sapphire occupied the central position in the front of the circlet of the Imperial State Crown, just under the Black Prince's Ruby. For the coronation of King George V it was displaced by the second Star of Africa diamond, and removed to the centre of the reverse side, a position which it still occupies.

5 EDWARDES RUBY

A fine crystal of ruby is exhibited in the Mineral Gallery of the British Museum (Natural History). It was given in 1887 to the Trustees by John Ruskin, and named by him 'In Honour of the invincible Soldiership and loving Equity of Sir Herbert Edwardes' Rule by the Shores of the Indus'. Major-General Sir Herbert Benjamin Edwardes, K.C.B., C.S.I. (1819–68), an able soldier and a wise administrator, probably saved British rule in India by maintaining friendly relations with Afghanistan and peace in the Punjab during the critical days of the Mutiny.

The crystal is translucent and of good colour, and shows a large basal plane with triangular markings. Its weight is 167 metric carats (nearly 1¼ oz.).

6 DEVONSHIRE EMERALD

In 1831 Dom Pedro, lately Emperor of Brazil, who had come to Europe after his abdication that year, gave to the sixth Duke of Devonshire a splendid natural crystal of emerald, a product of the famous mines at Muzo, Colombia, South America. It has the characteristic form of emerald, namely, an hexagonal prism terminated by a flat basal face, and, as is usual, it is rough at the other end, just as it was broken from the rock on which it had grown; as also is characteristic of Muzo emeralds, it is full of flaws, and for that reason no doubt it escaped being cut into stones for jewellery. A crack runs across one corner at the top, evidently due to a blow which it somehow received. A small piece of the original limestone matrix still adheres to a corner of the base. The crystal (fig. 117), measures about 2 inches (51 mm.) across and about the same in its greatest length, and weighs 1383·95 metric carats (nearly 10 oz.); its colour is the rich grass-green of the true emerald.

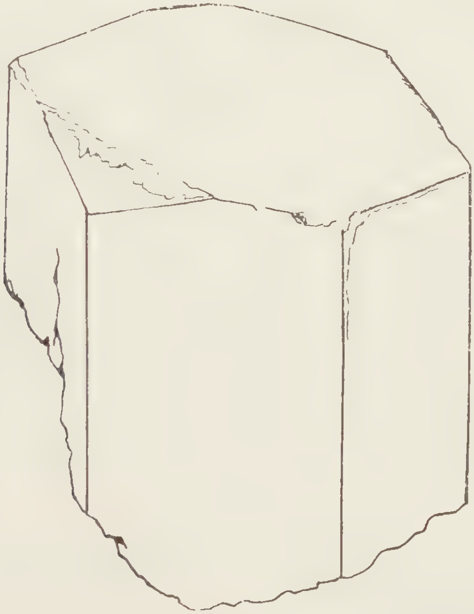

FIG. 117.—Devonshire emerald.

Of the history of the Devonshire Emerald little is known. The records at Chatsworth merely state that it was a gift from Dom Pedro in 1831. In the manuscript catalogue of the Allan-Greg collection[1] in the British Museum (Natural History) there is a reference to a fine emerald crystal, which unmistakably is the Devonshire emerald. The writer, Thomas Allan, entered against the date 1831 and the item 85 of Rhombohedral Emerald a description of the crystal in his collection, and goes on to say:

> 'In the hands of Mess Rundell & Co. I saw another fine cristal, weighing 8 oz. 18 pwts or 1043 carats, of a perfect form measuring across its diameter $2\frac{1}{4}$ $2\frac{1}{8}$ & $1\frac{7}{8}$ inches, & two inches in length.'

The firm in question were the Crown jewellers of that time: Rundell & Bridge. The weight as expressed in troy units is equivalent to 1384·10 metric carats, which within the limits of error is identical with that found for the Devonshire Emerald; the dimensions also agree. There is therefore no doubt that the emerald in the hands of Rundell & Bridge in 1831 was the one which came to the Duke of Devonshire that same year. Whether Dom Pedro acquired it from them or brought it from Brazil and for some reason left it with them is uncertain. It may be noted that in giving the figures for the weight in carats Allan made a slip of the pen; he should have written 1343 and not 1043 carats.

The Devonshire Emerald was shown at the Great Exhibition in Hyde Park, London, in 1851, though for some obscure reason not by the Duke of Devonshire but by James Tennant, the well-known mineral dealer in London of that date. The entry is on p. 14 of the *Official Catalogue*:

> '14 Tennant, J. 149 Strand.—Four cases of minerals and fossils for educational, scientific, and ornamental purposes. Large crystal emerald, &c., the property of the Duke of Devonshire.'

Since the Duke is stated to be the exhibitor of a large quartz crystal in item 531 of the same class, it is difficult to understand why he did not show the emerald as well. The Devonshire Emerald was shown again at the exhibition at the White City, London, in 1914, but does not appear in the catalogue. From July 1936 until January 1950 (except for the period of the second world war, when it was removed for safety) the emerald was lent by the Duke of Devonshire to the Trustees of the British Museum for exhibition in the Mineral Gallery at South Kensing-

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[1] This collection was purchased in 1860 by the Trustees of the British Museum from Robert Hyde Greg (1795–1875); it included the collection of Thomas Allan (1777–1833), an Edinburgh banker, which at his death was acquired by Greg.

ton. It was included in the Gemmological Association's exhibition in London in 1949, and was shown again in the City of Birmingham Museum in 1955.

7 HOPE CHRYSOBERYL

The superb faceted chrysoberyl, which was once with the more famous blue diamond in the Hope collection and on its dispersal was acquired by the Trustees of the British Museum, is exhibited in the Mineral Gallery of the British Museum (Natural History). Absolutely flawless, yellowish-green in colour, and 45 metric carats in weight, it is probably by far the finest cut example of this type of chrysoberyl known. The stone is described and illustrated in the catalogue of the collection.[1] The weight there given, namely 175 grains (that is 56·7 metric carats), must have been the total weight of the ring, the chrysoberyl, and the surrounding brilliants. The stone is represented in actual size on plate XVII.

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[1] '1. A most superb chrysolite, nearly of a circular form, and of a deep yellowish-green tint, approaching the peridot colour, and most admirably cut like a brilliant. This extraordinarily fine gem is of the greatest transparency and brilliancy, and free from any speck or flaw; its uncommonly large size and great perfection entitle it to be called a matchless specimen. It is certainly to be considered one of the rarest specimens of the cymophane, there being very seldom a stone of this size and weight found in this class of gems, which exhibits such perfection; set as a ring with small brilliants—vide plate 21. 175 grains.' B. Hertz, loc. cit., p. 56.

Part III

DESCRIPTION

Section A. Principal Stones

XIX

DIAMOND

Diamond has held pride of place as chief of precious stones ever since the discovery of the form of cutting known as the brilliant revealed to full perfection its amazing qualities; and justly so, since it combines in itself extreme hardness, high refraction, large colour-dispersion and brilliant lustre. A rough diamond, especially from river gravels, has often a peculiar greasy appearance, and is no more attractive to the eye than a piece of washing-soda. It is therefore easy to understand why the Persians in the thirteenth century placed the pearl, ruby, emerald and even peridot before it, and writers in the Middle Ages frequently esteemed it below emerald and ruby. The Indian lapidaries, who were the first to realize that diamond could be ground with its own powder, discovered what a wonderful difference the removal of the skin makes in the appearance of a stone. They, however, made no attempt to shape a stone, but merely polished the natural faces, and only added numerous small facets when they wished to conceal flaws or other imperfections; indeed, the famous traveller, Tavernier, from whom most of our knowledge of early mining in India is obtained, invariably found that a stone covered with many facets was badly flawed. The full radiant beauty of a diamond comes to light only when it is cut in the brilliant form. It may be noted that it has maintained the pre-eminence as well as inherited the name of the adamas of Pliny's day, but the mineral which he called adamas was clearly from his description not the same as the peerless gemstone which since medieval times has been known as diamond.[1]

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[1] 'The substance that possesses the greatest value, not only among precious stones, but of all human possessions, is adamas; a mineral which, for a long time, was known to kings only, and to very few of them. Such was the name given to a nodosity of gold, sometimes, though rarely, found in the mines, in close proximity with gold, and only there to be found, it was thought.' (Maximum in

The name of the species is derived from the popular form, *adiamentem*, of the Latin *adamantem*, itself the alliterative form of the Greek ἀδάμας, meaning the unconquerable, in allusion not merely to the great hardness but also to the mistaken idea that it would resist a blow. Bort probably comes from the Old-French *bord* or *bort* (bastard). Carbonado is a Portuguese word, carbonated, which was applied to the compact variety on its discovery in Brazil.

Diamond is the simplest in chemical composition of all the gemstones, being merely crystallized carbon, C. Impurities are often present, principally ferric oxide and silica with traces of lime and magnesia, but usually not beyond 5 per cent. It is the iron impurity which is responsible for the 'off-coloured' yellowish tinge which is so prevalent among diamonds, especially from South Africa, and detracts from their value. Carbon is dimorphic, the other crystalline form being graphite, sometimes known as blacklead or plumbago. Surely nature has surpassed all her marvellous efforts in producing from the same element substances with such divergent and contrasting characters as the hard, brilliant and transparent diamond and the soft, greasy and opaque graphite. Each of them has merits peculiar to itself. Besides its pre-eminence as a gemstone, diamond finds a demand in industry for cutting and abrasive purposes. Graphite, on the other hand, is the material used for the so-called lead pencils, as a polish for stoves, and, when mixed with clay, for refractory crucibles; it is, moreover, invaluable as a lubricant, especially for a heavy load. Both minerals exist in nature with no noticeable tendency to change from the one to the other. Indeed, a very high temperature (at least 1500° C.) is needed before any blackening of a diamond crystal, that is, its partial conversion into graphite, is effected by heating in the absence of oxygen. (When heated in oxygen, or even in air, diamond oxidizes to CO or CO_2 at temperatures above about 800° C.)

Bort, or boart as it is sometimes written, is a cryptocrystalline form in which the crystals of diamond are haphazardly arranged without definite orientation. The term is also used by jewellers for crystals and fragments of no service as gems, which are powdered and used for cutting and polishing purposes. Carbon, carbonado or black diamond also is a cryptocrystalline form, which is composed of a heterogeneous mass of still more minute crystals; it is black and opaque, or just translucent.

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rebus humanis, non solum inter gemmas, pretium habet adamas, diu non nisi regibus et iis admodum paucis cognitus. Ita appellabatur auri nodus in metallis repertus, perquam raro: comes auri, nec nisi in auro nasci videbatur.) Loc. cit., book 37, ch. 15.

The advantage of these cryptocrystalline masses is that the cleavage property of the individual crystals is masked, and they therefore possess the extreme hardness of diamond without its tendency to split under a heavy blow; for that reason such masses appear to be harder than ordinary diamond, and carbonado has been in great demand for use in cutting tools.

Diamonds, when absolutely limpid and free from flaws, are said to be of the 'first water', and are most prized when devoid of any tinge of colour except perhaps a bluish shade (plate VIII). Stones with a slight tinge of yellow are termed off-coloured, and are far less valuable. Attempts are sometimes made to improve off-coloured stones by coating the base facets with a blue film; usually it may be removed by washing the stone in benzol, methylated spirit or even hot water, but obstinate cases may call for the use of an acid. Stones of a canary-yellow colour, however, belong to a different category, and have a decided attractiveness. Greenish stones also are common, though it is rare to come across one with a really good shade of that colour. Brown stones, especially in South Africa, are not uncommon. Pink stones are less common, and ruby-red, mauve and blue stones are rare. Those of the last-named colour have usually what is known as a 'steely' shade, that is, they are tinged with green; stones of a sapphire blue are very seldom met with, and such command high prices. Piqué, a French word meaning pricked, and, from the effect of insect bites, spotted, is a term that is applied to diamonds exhibiting black specks of carbonaceous material in the interior.

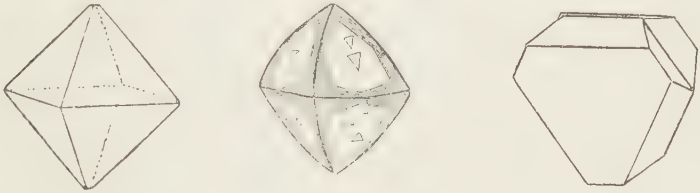

FIG. 118.—Diamond crystals.

Diamond crystallizes (fig. 118) in octahedra with brilliant smooth faces and occasionally in cubes with rough pitted faces; sometimes three or six faces take the place of each octahedron face, and the stone is almost spherical in shape. The surfaces of the crystals are often marked with equilateral triangles, which formerly were supposed to be the effects of incipient combustion, but by means of a multiple-beam interference method have been shown [1] to be the sites where growth-planes,

[1] S. Tolansky, *Microstructures of Diamond Surfaces*. London, 1955.

advancing with relative inclinations of 60° have met, but not coalesced. Shallow hollows, of irregular shape, are, however, due to etching and solution. The curvature of crystal edges, which often is present, is the result of the recessive stepping of growth-planes. Twinned crystals, in which the two individuals may be connected by a single plane or may be interpenetrating, a star shape often resulting in the latter case, are common; sometimes, if of the octahedron type, they are beautifully symmetrical. The rounded crystals are frequently covered with a peculiar gum-like skin, which is somewhat less hard than the crystal itself. A large South African diamond, weighing 133·145 metric carats and a nearly perfect octahedron in shape, which was the gift of John Ruskin, and named by him the 'Colenso' (p. 245) after the first Bishop of Natal, is exhibited in the British Museum (Natural History).

The determination of the crystal structure of diamond was one of the earliest successes of X-ray analysis. A packing drawing of a portion of the structure is given in fig. 40, and shows a part of the tetrahedral bonding which persists throughout the crystal. Detailed studies of the physical properties, such as the transparency to ultra-violet light, have shown that diamonds can be subdivided structurally into a normal Type I and a much rarer Type II (recently subdivided into Types IIa and IIb). Type I has been found to contain nitrogen as a major impurity. The ordinary physical properties, however, appear to be identical in all types, and the subdivision is of no significance in the use of diamond as a gem.

Carbonado has been found to have a cryptocrystalline structure composed essentially of minute interlocking crystals of diamond.

The refraction of diamond is single, but local double refraction is common, indicating a state of strain which can often be traced to an included drop of liquid carbonic acid; so great is the strain that many a fine stone has burst to fragments on being removed from the ground in which it has lain. The mean value of the refractive indices of colourless stones, corresponding to the yellow light of a sodium flame, is 2·4175, with the very small variation from it of 0·0003, a testimony to the purity of their composition; with increasing percentage of impurities the value of the refractive index rises to a maximum of 2·421, lying between that and 2·419 for off-coloured stones. The colour-dispersion is large, being as much as 0·044 for the *B*–*G* interval, in which respect it surpasses all colourless stones, but is exceeded by cassiterite, sphene (titanite) and the green garnet (demantoid) and also by synthetic rutile and synthetic strontium titanate. The lustre of diamond, when polished, is so characteristic as to be termed adamantine, and is due to the combination of high refraction and extreme hardness. Diamond, unlike glass, is transparent to X-rays. It phosphoresces under the action of rays beyond the violet end of the visible spectrum, even of those with such short wave-lengths as the radium emanations. Some, not all, diamonds fluoresce in ultra-violet rays, appearing blue or yellow-green; many will glow in the dark after exposure to sunlight, and a few even emit light when rubbed, the phenomenon known as triboluminescence (p. 141).

Colour can be induced artificially in diamond by irradiation. Bombardment with neutrons induces a green colour of an intensity depending upon dosage. If such a green diamond is heated the colour passes through various shades of yellow but cannot be removed completely even at high temperature. By bombardment with electrons a blue colour is induced. (Natural blue stones can be distinguished by their semi-conducting property.) The colours of these irradiated diamonds appear to be due to 'radiation damage' to the crystal structure, which is only partly restored by heating.

The specific gravity is reasonably constant, though it is necessarily more variable than the refractive index, because it is affected by the inclusion of gases or minerals, whereas the latter is not. The mean value for crystals is 3·520 with a possible variation of 0·010, off-coloured stones having values above the mean; for carbonado of fine quality 3·45 with a variation of 0·05, low-grade material being as low as 3·10; and for bort 3·501 with a variation of 0·004. Rather high values, about 3·60 have been claimed for Australian diamonds.

The following values of the refractive index and the specific gravity determined for particular diamonds may be noted; the stones, unless otherwise stated, are from South Africa. Refractive index: whites, 2·4174, 2·4175, 2·4177, 2·4184, 2·4186, 2·4188; canary-yellow, 2·4191; golden, 2·4205. Specific gravity, the weights in metric carats being stated in brackets: blue-white (11·504), 3·515; rough yellow-green, from Brazil (38·217), 3·521; octahedron, from India (57·627), 3·522; white (13·812), 3·527. In the case of each of the following diamonds the weight in metric carats is stated in brackets and is followed by the specific gravity and the refractive index: silver Cape (6·632), 3·523, 2·4190; Cape (11·740), 3·523, 2·4200; brown marquise (7·685), 3·518, 2·4180; reddish-brown (about 2), 3·518, 2·4192; steel-blue grey (5·055), 3·523, 2·4192.

Diamond is by far the hardest substance in nature and was marked by Mohs 10 on his scale, but the difference in hardness between it and corundum, which ranks as 9 on the scale, is enormous. It is difficult to make an absolute measurement of the hardness of diamond but various methods of measuring relative hardness have given figures indicating that it is between ninety and one hundred and eighty times as hard as corundum. Cutters have found by experience that the hardness varies perceptibly with the direction in the crystal, an octahedron face being the hardest and a cube face the softest direction, and these observations have been abundantly confirmed by many detailed investigations of directional grinding hardness in diamond. They also report that diamonds from Borneo and New South Wales are perceptibly harder than those from South Africa with which they usually have to deal. It is difficult to suppose that similar crystals can vary in hardness, and the paradox is probably due to the existence of twinning, which is imperceptible and cannot be detected by optical means, since the refraction is single. The metal tantalum and the artificial products, carborundum (silicon carbide) and borazon (cubic boron nitride), have a hardness which is comparable with that of diamond.

In spite of its extreme hardness, diamond will readily cleave under a heavy blow in planes parallel to the faces of the regular octahedron, or in other words it has four directions of cleavage; it was pointed out above (p. 172) that this property is utilized for shaping a stone previous to cutting it. Up to the beginning of the last century the fallacious but not unnatural idea was generally held that a diamond should, even if placed upon an anvil, resist a blow from a hammer[1]; indeed, this was supposed to be an infallible test for diamond and who knows how many fine stones were ruined through this illusion? The fact that diamonds could be split was known to Indian lapidaries at the time of Tavernier's visit, and it would appear from Boodt that in the sixteenth century the cleavability of diamond was not unknown in Europe, but it was not generally credited at the time and was soon forgotten. Early last century the celebrated chemist and mineralogist, the discoverer of palladium and rhodium, W. H. Wollaston, rediscovered the property, and, so it is said, used his knowledge to some profit by purchasing large stones, which, because of their awkward shape or the presence of flaws, had been rejected by the lapidaries, and selling them back again after cleaving them to suitable forms.

It has already been remarked above that the interval in hardness

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[1] The ancient tradition of the resistant property of adamas appears in Pliny's *Natural History*, and persisted for many centuries; but the white stone then known as adamas was not the modern diamond. 'These stones are tested upon the anvil, and will resist the blow to such an extent as to make the iron rebound and the very anvil split asunder.' (Incudibus hi deprehenduntur, ita respuentes ictum, ut ferrum utrimque dissultet, incudesque etiam ipsae dissiliant.) Loc. cit., book 37, ch. 5.

between diamond and corundum, which comes next to it in Mohs's scale, is enormously greater than that between corundum and the softest of minerals. Diamond can therefore be cut only with the aid of its own powder, and the cutting of diamond is therefore differentiated from that of other gemstones, the precious-stone trade being to a large extent divided into two distinct groups, namely, dealers in diamonds, and dealers in all other gemstones.

At the present day diamonds are mostly cut as brilliants, only small diamonds being cut as roses or points. With the increasing use of machinery for bruting the stones there is a tendency towards a circular contour for the girdle or a combination of two circles (the marquise), instead of the oblong contour, which was the original form, or the square contour, which has long been a favourite shape; a recent variant is an oblong form. For certain purposes, for instance, ear-rings and pendants, less symmetrical shapes, such as drop-forms, pendeloques or briolettes, are used. Sometimes the girdle is lozenge-shaped or may have even more curious forms. The perfect brilliant has fifty-eight facets, but small stones may have not more than forty-four, while exceptionally large stones may, with advantage, have many more. For instance, the largest stone, known as the Star of Africa, cut from the Cullinan mass has no fewer than seventy-four facets (p. 241). In the Jubilee-cut, again, there are as many as eighty-eight facets.

The description of the properties of diamond would not be complete without a reference to the other valuable, if utilitarian, purposes to which it is put. Without its aid much of modern engineering work and mining operations would be impossible, except at the cost of almost prohibitive expenditure of time and money.

Boring through solid rock has been greatly facilitated by the use of the diamond drill. The actual working part of the drill consists of a cast-steel ring. The crown of it has a number of small depressions at regular intervals into which the diamonds (now usually in the form of drilling bort, though carbonado has been much used) are embedded. On revolution of the drill an annular ring is cut, leaving a solid core which can be drawn to the surface. For cooling the drill and for washing away the detritus water is pumped through to the working face. The duration of the diamonds depends upon the nature of the rock and the skill of the operator. The most troublesome rock is one with sharp differences in hardness, because the diamonds are liable to be torn out of their setting. An experienced operator can tell by the feel of the drill the nature of the rock at the working face, and by varying the pressure can mitigate the risk of damage to the drill. Suitably shaped diamond crystals, polished to the required angles, are used in cutting tools for machining both metallic and non-metallic materials; tools impregnated with diamond powder also have many applications in industry.

The tenacity of diamond renders it most suitable for wire-drawing. The filaments used in electric lamps are prepared in this manner.

Although nearly all the gemstones scratch glass, diamond alone can be satisfactorily employed to cut it along a definite edge. Any flake at random will not be suitable, because it will tear the glass and form a jagged edge. The best results are given by the junction of two edges, which do not meet in too obtuse an angle; two edges of the rhombic dodecahedron meet the requirements admirably. The stones used by the glaziers are minute in size, being not much larger than a pin's head, and thirty of them on an average go to the carat. They are set in copper or brass. Some little skill is needed to obtain the best results.

The value of a diamond has always been determined largely by the size of the stone; the rate per carat advances with fair evenness up to 4 carats and jumps to a markedly higher level to reach the price of a 5-carat and larger stones. The rate would not be expected to continue to advance, and, indeed, a fall would be more likely, with an increase in the weight of a stone, because there is such a very restricted market for large stones. The rates for stones of poorer quality are proportionate very nearly to the weight, and do not rise with an increase in the weight.

The classification adopted for diamonds is as follows: (*a*) blue-white, (*b*) white, (*c*) fine silver Cape, (*d*) silver Cape, (*e*) light Cape, (*f*) Cape, (*g*) dark Cape, (*h*) fine light brown, (*i*) light brown, (*j*) brown and (*k*) dark brown. The term 'blue-white', however, has been so generally abused over a long period that its disuse has been recommended. By-water or bye is a term used for stones tinged with yellow; mélée are small stones of mixed sizes, weighing less than a $\frac{1}{4}$ carat, and mélange is the term used for larger stones of mixed sizes. In order to facilitate the grading of diamonds, apparatus has been devised which admits of the direct comparison of the stone under test with standard tints.[1]

With the discovery of the South African mines diamond rapidly became the commonest of gemstones, and the position was accentuated by the discovery of other productive fields in Africa. The output soon tended to exceed the potential absorption of the products in the world's commerce and industry, and it became abundantly clear to the leaders in the diamond mines that some form of control of the sale of diamonds

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[1] Robert M. Shipley and R. T. Liddicoat, 'A solution to diamond color grading problems,' *Gems and Gemology*, 1941, vol. 3, pp. 162–8.

was necessary as well as the merging of the numerous mine ownerships. Accordingly, the London Diamond Buying Syndicate was set up in 1893 with the object of disposing of the products of the mines to the best advantage and maintaining the level of prices by adjusting the output to the world's demand.

The arrangement worked satisfactorily for about thirty years until the discovery and development of other diamond fields, which were not represented in or controlled by the Syndicate, notably the deposits in South-West Africa, led to such excessive competition that the Syndicate ceased to exercise effective control. It was, however, still recognized that the system was satisfactory, and accordingly, in 1925, a new and enlarged Syndicate was formed to market the products of the diamond fields in South-West Africa, Angola, and the Belgian Congo, as well as those of the South African mines. The arrangement included the regulation of the output of the several areas by a quota system and the adjustment of payments to the producers by the average price obtained during six-monthly periods.

The agreement, however, ran for only five years and then came to an end, largely because the Government of the Union of South Africa were reluctant to allow the State diggings in Namaqualand to come under control. Eventually, in 1931, a new body, the Diamond Corporation, was set up with headquarters in South Africa, partly no doubt in order to escape the heavy taxation in London. The quota system was maintained, and the Government agreed to regulate the output of the State diggings proportionately, though, in order to stimulate the diamond-cutting industry in South Africa, they reserved the right to sell a minimum quantity of diamonds direct to the South African cutters. The Corporation is so powerful and its machinery so convenient that many small producers not represented in it have found it advantageous to entrust the marketing of their products to it.

The work of selling diamonds has since been placed in the hands of separate companies, the marketing of gem diamonds being dealt with apart from that of industrial diamonds. The Diamond Corporation continues to act as a link between the South African and other producers.

Diamond is most successfully imitated by 'fired' zircon, the colourless variety produced by heating, because of its high dispersion. Apart from its inferior hardness the latter may be distinguished by its double refraction and by the fact that on account of its lower refractivity some light always escapes at the back of a brilliant-cut stone; if any doubt still remains, the specific gravity may be determined. The other minerals producing colourless stones—corundum (white sapphire), topaz, and quartz (locally known as 'diamond')—have comparatively little fire; they are easily distinguished by the refractive indices. The commonest imitations are made of paste, and are easily recognized after a little wear by the scratches or other marks on the facets, apart from the inferior hardness and lower refraction.

Sometimes, in order to compensate for the yellowish tinge of an off-coloured stone and consequently to improve its appearance and value, the culet is concealed and painted blue. It is usually wise to examine carefully a stone which is not claw-set.

XX

OCCURRENCE OF DIAMOND

A. INDIA

The whole of the diamonds known in ancient times were obtained from the so-called Golconda mines in India. Golconda itself, now a deserted fortress near Hyderabad, was merely the mart where the diamonds were bought and sold. The diamond-bearing district actually spread over a wide area on the eastern side of the Deccan, extending from the Penner River north of Madras to the rivers Son and Ken, connected with the Ganges, in Bundelkhand. The richest mines, where the large historical stones were found, are in the south, mostly near the Kistna River. The diamonds were discovered in sandstone, or conglomerate, or the sands and gravels of river-beds. The mines were visited in the middle of the seventeenth century by the French traveller and jeweller, Tavernier, when travelling on a commission for Louis XIV, and he afterwards published a careful description of them and the method of working them (p. 238). The mines seem to have been exhausted in the seventeenth century; at any rate, the prospecting, which has been spasmodically carried on during the last two centuries, has proved almost abortive. With the exception of the Koh-i-nur, all the large Indian diamonds were probably discovered not long before Tavernier's visit. The diamonds known to Pliny, and in his time, were quite small, and it is doubtful if any stones of considerable size came to light before A.D. 1000. The small amount of mining that still persists is principally in the Bundelkhand district. The ancient Majgawan mine, in Panna State, Central India, which is now again being worked, appears to be in a volcanic pipe.

The famous stones mined in India include the following: Koh-i-nur, Pitt or Regent, Orlov, Sancy, Shah, Akbar Shah, Nassak, Taj-e-mah, Pigott, Eugénie, Hope, Austrian Yellow, Tuscany or Florentine, Star of Este, Polar Star, Nizam, Dresden White, Green and Yellow, Paul I, Cumberland and Pasha of Egypt, besides others which are known by tradition or description but which have disappeared (p. 238).

B. BRAZIL

India enjoyed the monopoly of supplying the world's demand for diamonds up to the discovery of diamonds in Brazil early in the eighteenth century. They were found (though not at first identified) in the gold washings at Tejuco, now called Diamantina, in the State of Minas Gerais, about 350 miles (560 km.) north of Rio de Janeiro. The discovery naturally aroused considerable excitement. So plentiful were the diamonds that only a few years after their discovery, in 1727, something like a slump took place in their value. In order to keep up the prices, the Dutch merchants, who mainly controlled the supply from India, asserted that the diamonds had not been found in Brazil at all, but were inferior stones shipped to Brazil from Goa. The tables were, however, neatly turned when diamonds were actually shipped from Brazil to Goa, and exported to Europe as Indian stones. Subsequently diamonds were discovered elsewhere in Minas Gerais and in several of the other States of Brazil. As the truth could no longer be concealed and in view of the increase in the supply of diamonds, their price tended to fall, but the drop was stayed by the action of the Portuguese Government, who exacted such heavy duties and imposed such onerous conditions that finally the mines ceased to be worked. Accordingly, in 1772 diamond-mining was proclaimed a royal monopoly, and such it remained until Brazil became an independent empire in 1822, when private mining subject to reasonable royalties was once more allowed. The industry was enormously stimulated in 1844 by the discovery of the remarkably rich fields in the State of Bahia, especially in the Chapada Diamantina district in the southern part of the State. It is here that carbonado, or black diamond, was first found, and to this area it is still restricted. Although after a few years the yield of diamonds from Brazil gradually declined, this country ranked for about a century and a half as the principal producer of diamonds in the world, until in fact its importance was overshadowed and finally eclipsed by the discovery and rapid development of the famous diamond fields in South Africa.

The most important of the diamond-producing areas in Brazil are in the States of Minas Gerais, Bahia and Matto Grosso, but in smaller quantities diamonds have been found in six other States also: Goyaz, São Paulo, Paraná, Piauhy, Maranhão and Amazonas.

In Minas Gerais the deposits are of two kinds: plateau or high-level, and valley (river) or low-level, the latter being the product of the former. The high-level deposits are mostly found high up, as much as 4000 and 5000 feet (1200 to 1500 m.) above sea-level, on the ridges between the river valleys, particularly on the Serra do Espinhaço, which runs nearly north and south. The diamonds occur in two distinct rock formations: the Itacolomy series, consisting of quartzites, sandstones, conglomerates and phyllites, including itacolumites, and believed to be of pre-Cambrian age; and the Lavras series, consisting of conglomerates, phyllites and sandstones, resting unconformably on the other, and believed to be of late pre-Cambrian or early Cambrian age. The series are traversed by dykes containing a soft altered rock, which is the diamond matrix. The minerals associated with the diamond are quartz, haematite and magnetite, with relatively smaller amounts of monazite, tourmaline, kyanite, xenotime, zircon and rutile.

The principal production of diamonds has, however, been in the *grupiáras*, the detrital deposits, and the *cascalho*, the gravel in river valleys, where the precious stone is found with large masses of quartz and small particles of gold. In some places modern dredging and diving equipment has been employed, but much of the mining is conducted by the natives in a very primitive fashion.

Carbonado occurs in the stream beds in the north of the State of Minas Gerais, and none has been found south of Grão Mogol, which lies about 50 miles (80 km.) north of Minas Novas. The pieces are picked by hand from the concentrates, considerable skill being required.

On the whole, the Brazilian diamonds, while comparatively small in size, have been of first-rate quality. Six large stones (p. 239) have been found: Star of the South, English Dresden, Star of Egypt, Star of Minas, Minas Gerais and Presidente Vargas, and there are reports of two more, the one of about 161½ carats from the Abaeté River in the State of Minas Gerais, and the other, of 600 carats, which was destroyed, from the Verissimo River in the State of Goyaz. An enormous mass of carbonado, weighing 3148 metric carats, which is more than the weight of the Cullinan diamond, was discovered at Lençoes, in the Chapada Diamantina district of the State of Bahia; it is reputed to have realized $17,380 (£3621 at par). Masses as large as 700 to 800 carats are known, but usually they run about 6 carats in weight.

C. SOUTH AFRICA

Early in 1867 the children of a Boer farmer, Daniel Jacobs, who dwelt near Hopetown on the banks of the Orange River, picked up in the course of play near the river a white pebble, which was destined not only to mark the commencement of a new epoch in the record of diamond mines, but to change the whole course of the history of South

Africa. This pebble attracted the attention of a neighbour, Schalk van Niekerk, who suspected that it might be of some value, and offered to buy it. Mrs Jacobs, however, gave it him, laughingly scouting the idea of accepting money for a mere pebble. Van Niekerk showed it to a travelling trader, by name John O'Reilly, who undertook to obtain what he could for it, on condition that they shared the proceeds. Everyone that he met laughed to scorn the idea that the stone had any value, and it was once thrown away and only recovered after some search in a yard, but at length he showed it to Lorenzo Boyes, the Acting Civil Commissioner at Colesberg, who, from its extreme hardness, thought it might be diamond and sent it to the mineralogist, W. Guybon Atherston, of Grahamstown, for determination. So uncertain was Boyes of its value that he did not even seal up the envelope containing it, much less register the package. Atherston found immediately that the long-scorned pebble was really a fine diamond, weighing $21\frac{3}{16}$ carats (21·73 metric carats), and with O'Reilly's consent he submitted it to Sir Philip Wodehouse, Governor at the Cape. The latter purchased it at once for £500, and dispatched it to be shown at the Paris Exhibition of that year. It did not, however, attract much attention; chimerical tales of diamond finds in remote parts of the world are not unknown. Indeed, for some time only a few small stones were picked up beside the Orange River, and no one believed in the existence of any extensive diamond deposit. However, all doubt as to the advisability of prospecting the district was settled by the discovery of the superb diamond, afterwards known as the 'Star of South Africa' or 'Dudley' (p. 243), which was picked up in March 1869 by a shepherd boy on the Zendfontein farm near the Orange River. Van Niekerk, on the alert for news of further discoveries, at once hurried to the spot and purchased the stone from the boy for five hundred sheep, ten oxen and a horse, which seemed to the boy untold wealth, but was not a tithe of the £11,200 which Lilienfeld Bros., of Hopetown, gave Van Niekerk.

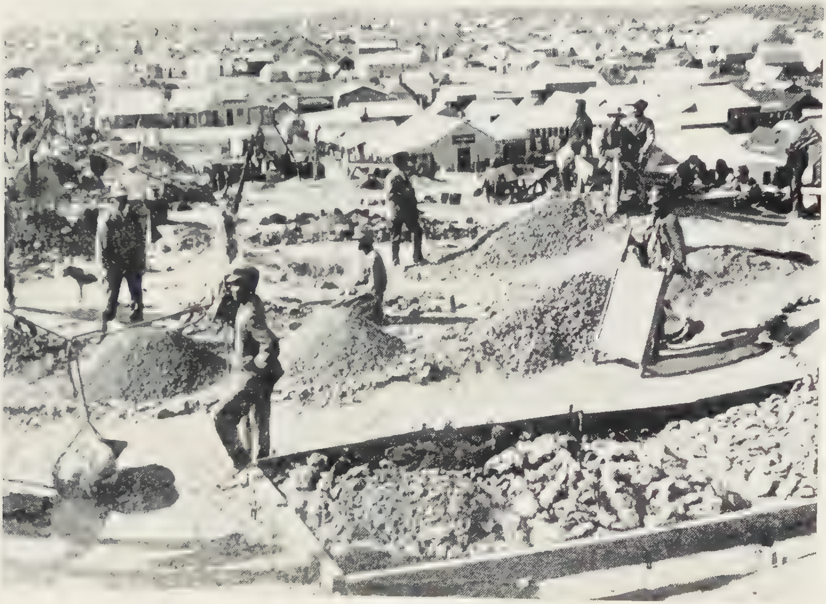
This remarkable discovery attracted immediate attention to the potentialities of a country which produced diamonds of such a size, and prospectors began to swarm into the district, gradually spreading up the Vaal River. For some little time not much success was experienced, but at length, early in 1870, a rich find was made at Klipdrift, now known as Barkly West, which was on the banks of the Vaal River immediately opposite the Mission camp at Pniel. The number of miners steadily increased until the population on the two sides of the river reached altogether some four or five thousand people, and there was every appearance of stability in the existing order of things.

A vast change came over the scene upon the discovery of still richer mines lying to the south-east and some distance from the river. The ground was actually situated on the route traversed by parties hurrying to the Vaal River, but no one dreamed of the wealth that lay under their feet. The first discovery was made in August 1870 at the farm Jagersfontein, near Fauresmith in Orange River Colony, by De Klerk, the intelligent overseer, who noticed in the dry bed of a stream a number of garnets, and, knowing that they often accompanied diamond, had the curiosity to investigate the point. He was immediately rewarded by finding a fine diamond, weighing 50 carats. In the following month diamonds were discovered about 20 miles (32 km.) from Klipdrift at Dutoitspan on the Dortsfontein farm, and a little later also on the contiguous farm of Bultfontein; a diamond was actually found in the mortar used in the homestead of the latter farm. Early in May 1871 diamonds were found about 2 miles (3 km.) away on De Beers' farm, Vooruitzigt, and two months later, in July, a far richer find was made on the same farm at a spot which was first named Colesberg Kopje, the initial band of prospectors having come from the town of that name near the Orange River, but was subsequently known as Kimberley (plates XVIII and XIX) after the Secretary of State for the Colonies at that time. Soon a large and prosperous town sprang up close to the mines; it rapidly grew in size and importance, and to this day remains the centre of the diamond-mining industry. Subsequent prospecting proved almost blank until the discovery of the Premier or Wesselton mine on Wesselton farm, about 4 miles (6 km.) from Kimberley, in September 1890; it received the former name after Rhodes, who was Premier of Cape Colony at that date. No further discovery of any importance was made until, in 1902, diamonds were found about 20 miles (32 km.) east of Pretoria in the Transvaal, at the new Premier mine, now famed as the producer of the gigantic Cullinan diamond.

The Kimberley mines were at first known as the 'dry diggings' on account of their arid surroundings in contradistinction to the 'river diggings' by the Vaal. The dearth of water was at first one of the chief difficulties in the way of working the former mines, although subsequently the accumulation of underground water at lower levels proved a great obstacle to the working of the mines. The river diggings were of a type similar to that met with in India and Brazil, the diamonds occurring in a gravelly deposit of limited thickness beneath which was barren rock, but the Kimberley mines presented a phenomenon hitherto without precedent in the whole history of diamond mining. The diamonds were found in a loose surface-deposit, which was easily worked, and for some time the prospectors thought that the underlying limestone corresponded to the bedrock of the river gravel, until at length one more curious than his fellows investigated the yellowish ground underneath, and found to his surprise that it was even richer than the surface layer. Immediately a rush was made back to the deserted claims, and the mines were busier than ever. This 'yellow ground', as it is popularly called, was much decomposed and easy therefore to work and sift. About 50 to 60 feet (15 to 18 m.) below the surface, however, it passed into a far harder rock, which from its colour is known as the 'blue ground'; this also turned out to contain diamonds. Difficulties arose as each claim, 30 by 30 Dutch feet in area (about 31 English feet or 9·45 m. square), was worked downwards. In the Kimberley mine (plate XVIII) access to the various claims was secured by retaining parallel strips, 15 feet (4·7 m.) wide, each claim being therefore reduced in width to 22½ feet (7 m.), to form roadways running from side to side of the mine in one direction. These, however, soon gave way, not only because of the falling of the earth composing them, but also because they were undermined and undercut by the owners of the adjacent claims.

By the end of 1872 the last roadway had disappeared, and the mine presented the appearance of a vast pit. In order to obtain access to the claims without intruding on those lying between, and to provide for the hauling of the loads of earth to the surface, an ingenious system of wire cables in three tiers (plate XIX) was erected, the lowest tier being connected to the outermost claims, the second to claims farther from the edge, and the highest to claims in the centre of the pit. The mine at that date presented a most remarkable spectacle, resembling an enormous radiating cobweb, which had a weird charm by night as the moonlight softly illuminated it, and by day, owing to the perpetual ring of the flanged wheels of the trucks on the running wires, twanged like some gigantic aeolian harp. This system fulfilled its purpose admirably until, with increasing depth of the workings, other serious difficulties arose. Deprived of the support of the hard blue ground, the walls of the mine tended to collapse, and additional trouble was caused by the underground water that percolated into the mine.

By the end of 1883 the floor of the Kimberley mine was almost entirely covered by falls of 'reef', as the surrounding rocks are termed, the depth then being about 400 feet (122 m.). In the De Beers mine, in spite of the precaution taken to prevent falls of reef by cutting the walls of the mine back in terraces, falls occurred continuously in 1884, and by 1887, at a depth of 350 feet (107 m.), all attempts at open working had



1. Kimberley Mine, 1871

2. Kimberley Mine, 1872

XVIII

1. Kimberley Mine, 1874

2. Kimberley Mine, 1911

to be abandoned. In the Dutoitspan mine buttresses of blue ground were left, which held back the reef for some years, but ultimately the mine became unsafe, and in March 1886 a disastrous fall took place, in which eighteen miners—eight white men and ten Africans—lost their lives. The Bultfontein mine was worked to the great depth of 500 feet (152 m.), but falls occurred in 1889 and put an end to open working. In all cases, therefore, the ultimate end was the same: the floor of the mine became covered with a mass of worthless reef, which rendered mining from above ground dangerous, and, indeed, impossible except at prohibitive cost. It was then clearly necessary to effect access to the diamond-bearing ground by means of shafts sunk at a sufficient distance from the mine to remove any fear of falls of reef. For such schemes co-operative working was absolutely essential. Plate XIX illustrates the desolate character of the Kimberley mine above ground and the vastness of the yawning pit, which is over 1,000 feet (300 m.) in depth.

A certain amount of linking up of claims had already taken place, but, although many men must have seen that the complete amalgamation of the interests in each mine was imperative, two men alone had the capacity to bring their ideas to fruition. Cecil James Rhodes (1853–1902) was the principal agent in the formation in April 1880 of the De Beers Mining Company, which rapidly absorbed the remaining claims in the mine, and was re-formed in 1887 as the De Beers Consolidated Mining Company. Meantime, Barnato[1] having amassed a small fortune of about £3000 by his astuteness in suspecting the existence of diamonds in the blue ground and buying cheaply the claims abandoned by owners, who thought them to be valueless on the exhaustion of the yellow ground, used it to secure the major interests in the Kimberley mine. Both men saw that, for effective working of the two mines by any system of underground working, they must be under one management, and the only, but important point at issue was which of them was to control the business. The story of the titanic struggle between these two men forms one of the epics of finance. Rhodes enlisted the support of the Rothschilds, and by the time that the shares in the Kimberley mine had been boomed to an extraordinary height, and the price of diamonds had fallen as low as 18*s.* a carat, Barnato found his opponent to be too strong and had to give way. In 1888 the Kimberley mine was absorbed by the De Beers Company on payment of the

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[1] Barnett Isaacs Barnato (1852–1897). The name Barnato was adopted by his elder brother, Henry, who had originally used it for professional purposes as an entertainer in the diamond fields and continued its use in his business as a diamond dealer. The younger brother also adopted the name when he joined the elder in South Africa.

enormous sum of £5,338,650, a new company being formed under the name of the De Beers Consolidated Mines. Shortly afterwards it undertook the working of the Dutoitspan and the Bultfontein mines, and in January 1896 it acquired the Premier or Wesselton mine. The interests in the Jagersfontein mine were in 1888 united in the New Jagersfontein Mining and Exploration Company, and the mine was worked also by the De Beers Consolidated Mines.

By far the largest of the South African pipes was discovered in the Transvaal in 1902 by Sir Thomas Cullinan, and was named by him the Premier. Its shape is approximately an oval, measuring about 1000 yards (900 m.) by 500 yards (450 m.), and its size is so enormous that it is anticipated that open working will be continued to a depth of 1000 feet (300 m.). The blue ground is excavated in a series of terraces 50 feet (15 m.) deep by drilling and blasting. For some years the Company marketed its own produce in London, but in 1916 it made an arrangement with the London Diamond Syndicate, and in 1922 the Company was absorbed in the De Beers Consolidated Mines. By 1931 the mine had been worked to the 660-foot level, but in the following year in consequence of the economic crisis operations were brought to a standstill. It was later reopened. In 1955 five pipe mines were being operated by De Beers Consolidated Mines Ltd, or by subsidiary companies. These were the Wesselton, Bultfontein, Dutoitspan and Jagersfontein mines in the Kimberley area and the Premier mine near Pretoria. It is intended to re-open the De Beers mine by 1964.

Among the many remarkable features attending the South African diamond mines not the least of them is the large number of stones of considerable size which have been produced, far more numerous than those known from all the rest of the world. In India and Brazil the discovery of a stone weighing upwards of 200 carats was a rare event, and caused great excitement and no little covetousness when it did occur. Stones of that kind were highly esteemed and were keenly sought for by great potentates. They passed into history, much of it of an apocryphal character, as has been pointed out in a previous chapter. In South Africa many more large stones have been mined than could possibly be used for ornamental wear. Apart from regalia and similar objects there is hardly anything for which they might be considered suitable. For modern dress large stones are not regarded with favour, and the weight is a militating factor. It is not surprising therefore that so many of the large diamonds discovered in South Africa are not only anonymous with no history, but have also been broken up into more serviceable sizes. In the long list, with dates of find, of stones at least 100 carats in weight, which Alpheus F. Williams has appended to his book [1] there are no fewer than sixteen between 400 and 500 carats, and as many as fourteen exceeded 500 carats (p. 246).

Though varying slightly in details, the methods of working the pipes by means of shafts are identical in principle. From the steeply inclined shaft horizontal galleries are run diagonally right across the mine, the vertical interval between successive galleries being 40 feet (12 m.). From each gallery side galleries are run at right angles to it and parallel to the working face. The blue ground is worked systematically backwards from the working face. The mass is stoped, i.e. drilled and broken from the bottom upwards, until only a thin roof is left. As soon as the section is worked out and the material removed, the roof is allowed to fall in, and work is begun on the next section of the same level; at the same time the first section on the level next below is opened out. Thus work is simultaneously carried on in several levels, and a vertical plane would intersect the working faces in a straight line obliquely inclined to the vertical direction (fig. 119). When freshly mined, the blue ground is hard and compact, but it soon disintegrates under atmospheric influence. Indeed, the yellow ground itself is merely decomposed blue ground. At first, no immediate attempt was made to retrieve the precious stones. The blue ground was spread on to 'floors', spaces of open veldt which had been cleared of bushes, to a depth of a couple of feet. There it remained for a period ranging from six months to two years, depending on the quality of the blue ground and the amount of rainfall.

To hasten the disintegration the blue ground was frequently ploughed over and occasionally watered, a remarkable introduction of agricultural methods into mining operations. No elaborate patrolling or guarding was required, because the diamonds are so sparsely, though regularly, scattered through the mass that even of the actual workers in the mines but few have ever seen a stone in the blue ground. When sufficiently broken up, it was carted to the washing and concentrating machines (plate XXI), by means of which the diamonds and the heavier constituents are separated from the lighter material. Subsequently this period of exposure of the blue ground to weathering was eliminated. The ore is crushed (initial crushing is carried out underground at some mines) and primary gravity concentration is effected by a floatation method, using ferro-silicon as the heavy medium in which the lighter gangue minerals rise to the surface.

Formerly the diamonds were picked out from the concentrates by

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[1] *The Genesis of the Diamond*, London, Ernest Benn Limited, 1932, pp. 619–35.

means of the keen eyes of skilled natives; but the process has been vastly simplified and the risk of theft entirely eliminated by the remarkable discovery made in 1897 by F. Kirsten, of the De Beers Company, that of all the heavy constituents of the blue ground diamond alone, with the exception of an occasional corundum and zircon, which are easily sorted out afterwards, adheres to grease more readily than to water. In this ingenious machine, the 'jigger' or 'greaser' (plate XXI), as it is commonly termed, the concentrates are washed over a series of galvanized-iron trays, which are covered with a thick coat of grease. The trays are slightly inclined downwards, and are kept by machinery in constant sideways motion backwards and forwards.

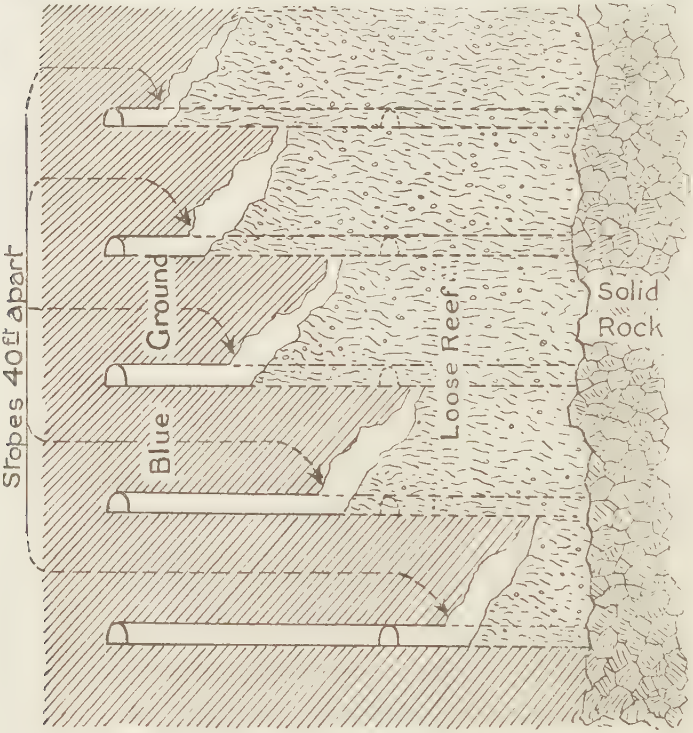

FIG. 119.—Diamond pipe: vertical section.

Preliminary gravity concentration is also used in the alluvial fields, but it was found that with these diamonds the grease-table process was ineffective. The diamonds would not adhere to the grease and the whole concentrate had to be subjected to hand-sorting, a process in which many small stones were overlooked. The Diamond Research Laboratory developed a process for 'conditioning' the diamonds, and thus causing them to adhere. Unfortunately this conditioning also enables some of the finer waste particles likewise to adhere; a moving grease-belt is therefore used in place of the grease-table to present a continually fresh surface. In the electrostatic process use is made of the fact that diamond is virtually non-conducting, whereas most of the waste particles are better conductors. The dried concentrate is passed through a high-tension field maintained between two electrodes. The induced charge leaks more rapidly from the waste than from the diamonds, which are thus not attracted towards the positive electrode which deflects the waste.

The classification at the mines is first into groups by the shape: (1) close goods, (2) spotted stones, (3) rejection cleavage, (4) fine cleavage, (5) light brown cleavage, (6) ordinary and rejection cleavage, (7) flats, (8) macles, (9) rubbish, (10) bort. Close goods are whole crystals, which contain no flaws and can be cut into single stones. Spotted stones, as their name suggests, contain spots which necessitate removal, and cleavage includes stones, which are so full of flaws that they have to be cleaved or split into two or more stones. Flats are distorted octahedra, and macles are twinned octahedra. Rubbish is material which can be utilized only for grinding purposes, and bort consists of round dark stones, which are invaluable for rock-drills. These groups are afterwards graded into the following subdivisions, depending on increasing depth of yellowish tint: (*a*) blue-white, (*b*) first Cape, (*c*) second Cape, (*d*) first bye, (*e*) second bye, (*f*) off-colour, (*g*) light yellow, (*h*) yellow. It is, however, only the first group that is so minutely subdivided. After being purchased, the parcels are split up again somewhat differently for the London market (p. 264), and the dealers rearrange the stones according to the purpose for which they are required. The arrangements for marketing the diamonds from the Kimberley mines are described in the previous chapter.

The products of each mine show differences in either form or colour, which enable an expert readily to recognize their origin. The old diggings by the Vaal River yielded finer and more colourless stones than those found in the dry diggings and the mines underlying them. The South African diamonds, taken as a whole, are always slightly yellowish or off-coloured; the mines are, indeed, remarkable for the number of fine and large, canary-yellow and brown, stones produced. The Kimberley mine yields a fair percentage of white, and a large number of twinned and yellow stones. The yield of the De Beers mine comprises mostly tinted stones—yellow and brown, occasionally silver Capes, and very seldom stones free from colour. The Dutoitspan mine is noted for its harvest of large yellow diamonds; it also produces fine white cleavage and small white octahedra. The stones found in the Bultfontein mine are small and spotted, but, on the other hand, the yield has been unusually regular. The Wesselton mine yields a large proportion of flawless octahedra, but, above all, a large number of beautiful deep-orange diamonds. Of all the South African mines the Jagersfontein in the Orange River Colony alone supplies stones of the highly-prized blue-white colour and steely lustre characteristic of the old Indian stones. The Premier mine in the Transvaal is prolific, but mostly in off-coloured and low-grade stones, the Cullinan diamond being a remarkable exception.

The principal minerals which are associated with diamond in the blue ground are magnetite, ilmenite, pyrope garnet (which has been put on the market under the misnomer 'Cape-ruby'), enstatite, more or less decomposed olivine, zircon, kyanite and mica.

To illustrate the amazing productiveness of the South African mines, it may be mentioned that the De Beers and Kimberley mines from 1889 to 1914 yielded nearly thirty-eight million carats of diamonds, whereas the total output of the Brazil mines, for the whole of the long period during which they have been worked, has barely exceeded thirteen million carats. The average yield of the South African mines, however, perceptibly diminishes as the depth increases.

As has already been pointed out the impossibility of satisfactorily working the diamond pipes except as units compelled the various and numerous interests to join together and finally merge into one single combine. The river diggings and detrital deposits generally, on the other hand, lent themselves to exploitation on a small scale and to working by individual owners or at least quite small companies. Consequently the yield from the deposits was small compared with the produce of the pipes, and, while that was so, the De Beers Company held unchallenged supremacy in the diamond world and experienced no difficulty in adjusting the diamond output to the world's demand so that the price level was maintained. The position was not seriously affected by the discovery and exploitation of diamond fields in South-West Africa and in the Belgian Congo, because the output was controlled in each instance. A serious situation, however, arose with the discovery, about the same time, in 1925 and 1926, of two rich fields in South Africa, the one in the Transvaal and the other in Little Namaqualand. Their output was so large that the yield for alluvial deposits overtook and in 1928 even surpassed that for the mines. With the multiplicity of small ownerships limitation of output by agreement was out of the question, and it was quickly realized that, unless suitable measures were taken forthwith, serious disaster must befall the diamond industry, upon which the prosperity of the Union of South Africa to no small degree depends. Accordingly, in November 1927 the Government passed an amended Precious Stones Control Act, whereby the mining and marketing of precious stones is vested in the Crown, and the Governor-General was given power to make regulations to restrict the output from the alluvial fields and the prospecting for new areas.

In the Transvaal the diamantiferous gravel occurs on a cherty conglomerate in a dolomitic limestone in the Lichtenburg-Vertersdrop district on the west. Although the field was discovered only in 1926, in the following year it produced about four-fifths of the yield of the alluvial fields of South Africa. The product consists mainly of small stones.

Although deposits were found near Port Nolloth, on the coast of Little Namaqualand in 1925, and a systematic search revealed an extensive field running along the coast southwards from the Orange River, development proceeded with comparative slowness owing to the inaccessibility and inhospitable character of the country. The deposits appear to have been left by the sea at different levels as it receded, and in the rich field to the north-east of Alexander Bay there is an unusual association of diamond with a fossil oyster shell (*Ostrea prismatica*) in a bed, which is known as the Oyster Line. This field is notable for the remarkably fine lot of stones which were found in the course of prospecting; they were valued at over £12 per carat and the largest stone, which weighed 71·5 carats, fetched £8000. Under the powers of the Act mentioned above the Government rigorously limits the exploitation and development of the deposits in this region.

The distribution of the diamonds is irregular and they are usually buried under sand, barren gravel or limestone. As in South-West Africa some at least of the stones have been washed up by the sea, from areas under water, but some of them were no doubt brought down by rivers from inland. Their origin in either case is uncertain.

D. SOUTH-WEST AFRICA

At the time of its discovery, 1908, the occurrence of diamond in South-West Africa was without parallel or precedent, but in 1925 similar deposits were found south of the Orange River. Small stones running about four to seven to the carat, were discovered close to the shore near Luderitz Bay in a gravelly surface layer, which is quite shallow, its thickness being usually only a few inches, though here and there it is as much as 30 feet (9 m.). The stones are usually hexoctahedra or twinned octahedra, simple octahedra being rare. The associated minerals are quartz, chalcedony, agate, almandine, epidote, haematite and magnetite.

The deposits have been found to extend, though not continuously, from Conception Bay to Chameis, but principally they lie near Lüderitz and to the south of it. Following upon the discovery of the deposits to the south of the Orange River, prospecting has brought to light similar deposits. Before the first world war the deposits were worked by sixteen different companies, the output being controlled by the German Government and sold through the Diamant Regie in Berlin to a syndicate at Antwerp. Since the war the principal firm working the fields has been the Consolidated Diamond Mines of South-West Africa, another important company being Namaqua Diamonds. The development of the fields was checked by the economic crisis, and it is now regulated by the Government under the Precious Stones Control Act. Owing to the irregular distribution of the diamonds in the gravel containing them, the deposits have to be worked on a big scale by means of mechanical excavators. The gravel is sent to a plant for treatment, either at Elizabeth Bay or at Kolmanskop. It is crushed and concentrated, and the diamonds were at first picked out by hand, since grease-tables will not work in these plants unless the diamonds are conditioned (p. 277).

E. WEST AFRICA

In 1910 diamonds were first found in the Belgian Congo in the bed of the Kiminina River near the Mai Munene waterfall, and so promising were the indications that a systematic exploration was undertaken by the Société Internationale Forestière et Minière du Congo (commonly shortened to Forminière) with the resulting discovery of the largest known diamond field, which extends into the neighbouring territory of Angola, where the deposits are worked by the Companhia de Diamantes de Angola (commonly shortened to Diamang), which is an offshoot of Forminière. The field is estimated to extend over 150,000 sq. miles (390,000 sq. km.). It has developed into the world's most important source of diamonds, producing in 1954 60 per cent by weight of the world output of 20,515,000 metric carats. Only a few per cent of these were of gem quality, however, the remainder being for industrial use.

The diamond-bearing gravels occur in rivers of varying size, which traverse a plateau of nearly horizontal sandstones of Jura-Triassic age.

The stones are usually small in size, averaging about eight to twelve to the carat, but may reach as large a size as 44 carats; their quality ranges from blue-white to bort. The associated minerals include quartz, staurolite, kyanite, ilmenite, tourmaline, chrysoberyl and garnet; in the Bushimaie valley in the Congo there is no staurolite, diopside being present with ilmenite and garnet. The gravels are mechanically concentrated and screened, and the diamonds are picked out by hand. This system entails the great difficulty of the prevention of theft of stones.

Alluvial deposits yielding diamonds have also been found in parts of former French Equatorial Africa adjacent to the Congo on the north and west—in the basin of the Kotto River, Central African Republic, in former French Congo, and in Gabon.

Following upon the discovery of a diamond in 1919 by Sir Albert Kitson at Abomoso near the Birim River rich fields have come to light in Ghana (Gold Coast). The stones are very small in size, averaging only about thirty-five to the carat, and the largest found weighed under 4½ carats; nevertheless, an extensive trade has been done in them for industrial purposes. Since 1957 Ghana has become the second largest producer of diamonds in the world, after the Congo. The associated minerals are mainly staurolite and ilmenite. Larger diamonds, one of which weighed 10½ carats, have been found in the gravels of the White Volta River in the Northern territories.

In 1930 two clear diamonds, weighing about a ¼ carat each, were discovered in quartz gravel on the bank of the Gbobora River by the Geological Survey of Sierra Leone. As the result the Consolidated African Selection Trust of the Gold Coast sent a prospecting party in 1931, and eventually were given the exclusive right of prospecting over a large area in eastern Sierra Leone. Rich fields were brought to light, the stones varying in quality from bort to the finest blue-white, and in size from small stones, averaging ten to twelve to the carat, up to one, weighing 144 carats. A fine stone, weighing 78 carats, was sold for £5000; an enormous stone, weighing about 530 carats (3¾ oz.) was discovered in 1943, and an even larger one, weighing about 770 carats (5½ oz.) in 1945, the latter being surpassed in size only by the Cullinan and the Excelsior. There is every indication that the diamond fields of Sierra Leone will have a long life.

A further important producing area lies north of Sierra Leone in the Haute Guinée region of former French West Africa, now the independent Republic of Guinea. A high proportion of the output is of gem quality.

F. CENTRAL AND EAST AFRICA

In 1903 small diamonds were found in gravel beds, resting on decomposed granite, near the Somabula Forest, about 12 miles (19 km.) west of Gwelo, in Southern Rhodesia, the associated minerals being chrysoberyl in abundance, blue topaz, kyanite, ruby, sapphire, tourmaline and garnet. The field is not rich, and little systematic work has been done since 1908.

Diamonds have been known to exist in Tanganyika as far back as 1910, but no work on a commercial scale was attempted before 1925. The field lies to the south of Lake Victoria. The first discovery was made at Mabuki, 36 miles (58 km.) south-east of Mwanza on the lake. Diamonds were later found also near Shinyanga and on the Iramba Plateau, some hundred miles farther south. More than forty pipes were located in the area, but they proved nearly barren, and it seemed probable at first that the diamondiferous surface deposits had been conveyed from elsewhere and were not connected with the present pipes. In 1940, however, John T. Williamson (1907–1958) discovered at Mwadui a pipe 3500 feet in diameter from which a large production has since been maintained. The largest stone recorded is one of 240·83 carats found in 1956; a stone of about 67 carats was named the Battershill, after the Governor, Sir William Battershill, who happened to visit the mine the day of its discovery. A pink diamond of 54½ carats was presented by Dr Williamson to Her Majesty Queen Elizabeth II, then Princess Elizabeth, on the occasion of her marriage; it was shown mounted in a flower-brooch at an Exhibition, 'The Ageless Diamond', in London in 1959. The mines were purchased jointly by the Government of Tanganyika and De Beers Consolidated Mines Limited in 1958.

G. OTHER COUNTRIES

The occurrence of diamonds in Borneo and Indonesia has been known since very early times. The most important fields are by the Landak River, near Pontianak, in the extreme west, and round Martapoera, near Bandjermasin, in the south-east. They are usually found in rather coarse gravel, in association with corundum and rutile together with the precious metals, gold and platinum. Indeed, it is said to be no uncommon sight to see natives wearing waistcoats ornamented with gold buttons, in each of which a diamond is set. The diamonds are well crystallized and generally of pure water; yellowish and canary-yellow stones are also common, but rose-red, bluish, smoky and black stones are rare. They seldom exceed a carat in weight, and average four to the carat; stones of 10 carats in weight have, however, been found and occasionally they attain to 20 carats. Borneo diamonds are reputed to be unusually hard, probably because of intimate twinning (p. 262).

In 1850 a large diamond, weighing 77 carats, is reported to have been found. The large and historical Mattan stone (p. 246) in the possession of the Rajah of Mattan is probably quartz.

Diamonds were found in New South Wales as long ago as 1851, on Turon River and at Reedy Creek, near Bathurst, about 90 miles (145 km.) from Sydney; but the find was of little commercial value. A more extensive deposit came to light farther north, at Mudgee, in 1867. In 1872 diamonds were discovered in the extreme north of the State near the Queensland border. In 1884 another discovery was made at Tingha, and in 1904 it was found in the tin washings at Inverell in the same region.

The diamonds are of excellent quality, being free from colour and well shaped. They are not large, the cut stones averaging about five to the carat and the largest, when cut, being just under 6 carats in weight. Like the Borneo stones the Australian diamonds had the reputation of being so hard that they could be cut only with their own powder, ordinary diamond dust making no impression. This statement is founded on a fallacy, since there cannot be any essential difference in hardness. If, however, the diamonds are so intimately twinned that the twinning is not apparent to the eye, it is quite likely that the directions of relative softness are thus obscured.

Although a diamantiferous belt, some 10 to 30 miles (15 to 50 km.) in width, has been proved to run across nearly the whole of British Guiana, parallel to the coast and about 100 miles (160 km.) inland, it has been comparatively little exploited, because its general inaccessibility prevents economic working; but as the country is opened up the industry may grow in importance. The diamonds mostly occur in the gravels of rivers and streams, the most important areas being those by the five rivers: Mazaruni, Puruni, Potaro, Cuyuni and Berbice. The associated minerals are quartz, chalcedony, rutile, tourmaline, topaz, corundum, garnet, ilmenite and gold. The diamonds on the whole are small in size, averaging about six to the carat, but occasionally they attain to 10 carats; the largest, which was found in 1926 at the Potaro River, weighed 56 carats.

The first discovery of diamond was as far back as 1887 in the gold-washings at the Puruni River, but on account of the difficulty of access development has been slow. The exploitation has been mainly in the hands of small owners and the methods of extraction have mostly been primitive. The company formed in 1926 under the name of United Diamond Fields of British Guiana was wound up two years later.

Many isolated finds of diamond have from time to time been reported in various parts of the United States, but none of them has proved to be of great importance. Diamonds were found in the gold-washings of California as far back as 1850. The field near Manchester, Virginia, is noteworthy for producing in 1885 the 'Dewey' diamond, an octahedron with rounded edges, weighing 23¾ carats (24·4 metric carats), at that date the largest stone known from the United States. The most important field in the United States at the present time was discovered in 1906 near Murfreesboro in Arkansas; the largest stone found there, an irregular octahedron in shape, weighed 40·22 metric carats and more than 50,000 diamonds have been recovered from four small areas of ultrabasic igneous rock resembling kimberlite.

Diamonds in limited quantity occur in river gravels in Venezuela, and have also been found in northern Hunan Province, Central China. In Russia, there has long been a small output from alluvial deposits in the Ural Mountains. In 1949 much richer alluvial deposits were located in the basin of the River Vilui, in the Republic of Yakutia on the Siberian Plateau; five years later the first discovery was made of a primary deposit in a kimberlite pipe. A series of further discoveries has disclosed an extensive diamantiferous province, covering some 120,000 sq. miles (300,000 sq. km.) in this part of Siberia. Most of the stones are small, with a large proportion of fragments and splinters of industrial quality, but the Government of the U.S.S.R. hope to achieve an output comparable with those of Congo and Ghana.

XXI

ORIGIN OF DIAMOND

By far the most abundant of precious stones is diamond. We have seen that it carpets large areas in Africa and is even scattered, regularly if sparsely, throughout the material filling apparently bottomless vents in the earth in South Africa, and is also found, though not in such quantity, in India and South America; moreover, there may still remain many extensive fields for discovery in Asia, as well as in the continents where they are already known. It may therefore seem incongruous that diamond retains its pre-eminent position in the world of jewellery, in spite of the fact that it offends against one of the essential canons of a precious stone—rarity. The explanation is possibly quite simple: namely, that the diamond output is carefully controlled, so that the price level is free from violent fluctuations, and, in consequence of its unique hardness and the labour thus entailed in cutting them, faceted diamonds cannot but be relatively costly.

The diamond pipes in South Africa, apart from their considerable commercial value, are of exceptional scientific interest because of the light which they shed upon the origin of the diamond, a problem which has long baffled the scientific world. It must, however, be confessed that despite the large amount of research which has been done by many investigators, and despite the thought which has been devoted to it by many philosophers, the problem cannot be said to have been completely solved.

In other types of diamond field in different parts of the world the gravel, conglomerate, sandstone, metamorphic schist, or whatever be the rock from which the diamonds have been extracted, variable as their character may be, have nevertheless one feature in common—none of them is the parent rock of the precious mineral. In these instances the deposit has formed round the diamonds, having been transported by the agency of water, usually rivers or streams but possibly the sea also, and is itself the product of the disintegration of still older rocks through which the water had passed; it is probable that certain of the minerals found in association with the diamond may have originated with it and have accompanied it through the whole course of its adventurous journey. Hard as they are, diamonds sometimes show unmistakable signs of attrition, testifying to the immense distance through which they must have travelled.

The occurrence at Kimberley is very different in character. These mines are mere funnels, more or less oval in section and narrowing with increasing depth, which go downwards to unknown depths and are evidently the result of some eruptive agency. The Kimberley mine has been worked to a depth of nearly 4000 feet (1200 m.), and no signs of an end have yet been met. It must, however, not be overlooked that this depth of about three-quarters of a mile, great as it may appear to us, is small compared with the mean diameter of the earth, about 7900 miles (12,720 km.), and represents relatively a very small prick of the surface of the globe. The blue ground filling the pipes must clearly have been forced up from remote depths, since it is entirely unrelated to the country rocks surrounding them. The blue ground itself is an altered and brecciated basic (that is without free silica) igneous rock, which is allied to a rock rich in olivine (peridot) and therefore known as peridotite (p. 216). Carvill Lewis,[1] who first studied it, gave it the scientific name of kimberlite from the place where it was first found. Its blue colour testifies to the richness in iron, and it is to the oxidation of the iron constituent that the change of colour to yellow in the upper levels is due.

From the shafts that have been sunk for working the mines, the nature of the surrounding rocks is known to a considerable depth. Immediately below the surface is a decomposed ferriferous basalt, about 20 to 90 feet (6 to 27 m.) thick, next a black slaty shale, 200 to 250 feet (60 to 75 m.) thick, then 10 feet (3 m.) of conglomerate, next 400 feet (120 m.) of olivine diabase, then quartzite, about 400 feet (120 m.) thick, and below this a quartz porphyry. This may reach a thickness of 1000 feet (300 m.). In the De Beers Mine it rests directly on the granite of the Basement Complex into which the deeper shafts finally penetrate. In the Kimberley Mine a further 300 feet (90 m.) of sediments are found beneath it, resting on the granite. The strata run nearly horizontal, and there are no signs of upward bending at the pipes. The whole of the country, including the mines, was covered with a red sandy soil, and there was nothing to indicate the wealth that lay underneath. The action of water had in process of time removed all signs of eruptive activity.

The evidence resulting from the examination both of the blue ground and of the walls of the pipes shows that these vents were not volcanoes,

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[1] Henry Carvill Lewis (1853–88), *The Genesis and Matrix of the Diamond*, edited by T. G. Bonney, London, New York, and Bombay, 1897, p. 50.

because there is no indication of the action of excessive temperature, such as would for instance be implied were there any metamorphism (alteration) of the rocks forming the walls of the pipes, whereas there are abundant signs of the operation of enormous pressures. Crookes has put forward the theory, which may be accepted, that the agency which hurtled the blue ground and the diamond contained in it up the channel to the surface was the gaseous form of water—steam. From the evidence presented by these pipes we therefore learn that, whatever may be the conditions under which diamond occurs, it was formed in the depths of the earth and reached the surface by propulsion up a pipe of the kind familiar at Kimberley. In the various diamantiferous deposits the diamond may have travelled far from the place of emission, and a long time, even from the geological point of view, may have elapsed since it reached the surface. It cannot therefore be expected that a diamond field can be related to known pipes, since the pipes which gave rise to the field were obliterated by later depositions, and may, indeed, now be buried deep beneath later rock formations. At Majgawan, India (p. 267), Mwadui, Tanganyika (p. 282), Murfreesboro, Arkansas (p. 284) and Yakutia, U.S.S.R. (p. 284), however, production is from pipes.

There still remains the question: Where and how has the diamond crystallized? We know the earth to have a density of 5·527, and to consist of a central core of metallic iron, probably in a liquid state, and an outer shell, with a general composition corresponding to olivine. The diameter of the core bears a ratio of 0·55 to that of the earth. Seismological observations have shown that the average density of the outer shell is 4·5. From this value, the density of the earth, and the relative diameter of the core, it can be calculated that the density of the core is 12·0. Since the density of the surface rocks is about 3 on the average, and that of olivine is 3·4, the inner part of the outer shell must be greatly compressed if the average density of the whole shell is to be 4·5. It is clear that, as a consequence of the rise of temperature with increasing depth and the pressure exerted by the superincumbent solid upper layers, the lower layers are plastic and highly compressed. Similarly, the necessarily enormous state of compression of the core will account for its density being so much higher than that of terrestrial iron (about 7). The pipes obviously perforated the solid portion of the upper crust, and it is the underlying plastic rock, akin to olivine (peridot), which with the concomitant material is shot up through them, and appears as the blue ground.

Three theories have been advanced regarding the crystallization of the diamond:

(*a*) The volcanic material had brought up and dissolved the deep-seated rock in which the diamond had originally been formed;

(*b*) The deep-seated carbonaceous material had been dissolved by the volcanic rock and had crystallized as diamond under high temperature and great pressure;

(*c*) The diamond was an original constituent of the blue ground, which remained unaltered by the changes in the other materials due to the action of steam.

All the lines of evidence point to the third of these theories being the correct one. That diamond has been found in a meteorite is not surprising, if it be granted that the iron and stony meteorites are fragments of the earth's interior, which were so violently erupted as not immediately to fall on the surface. The fact that the diamonds from each of the pipes in South Africa have their peculiarities, which enable the expert to identify the one which yielded them, is evidence that the source of the contents of any pipe and the material which has emanated from it was at or close to its lower end.

XXII

CORUNDUM

Ranking in hardness second to diamond alone, the species known to science as corundum and widely familiar by the names of its varieties, sapphire and ruby, holds a pre-eminent position among coloured gemstones. The barbaric splendour of ruby (plate VIII, 13) and the glorious hue of sapphire (plate VIII, 2-4) are unsurpassed, and it is remarkable that the same species should boast such different, but equally magnificent, tints. They, however, by no means exhaust the resources of this variegated species. Fine yellow stones (plate VIII, 6), which compare with topaz in colour and are its superior in hardness, and brilliant colourless stones, which are unfortunately deficient in fire and cannot therefore approach diamond, are to be seen, besides others of less attractive hues: purple, and yellowish, bluish and other shades of green. Want of homogeneity in the coloration of corundum is a frequent phenomenon; thus, the purple stones on close examination are found to be composed of alternate blue and red layers, and stones showing patches of yellow and blue colour are common. Owing to the peculiarity of their interior arrangement certain stones display, when cabochon-cut, a vivid six-rayed star of light. Sapphire and ruby share with diamond, pearl and emerald the first rank of jewellery. They are popular stones, especially in rings; their comparative rarity in large sizes, apart from the question of expense, prevents their use in the bigger articles of jewellery.

As has been stated above, the species is known in mineralogy as corundum, the blue variety being sapphire and the red variety ruby. In commerce, however, the word is applied to the opaque stones, which are crushed to powder and used for abrasive purposes, in order to distinguish the purer material from emery, which also is powdered corundum, but mixed with magnetite and other heavy minerals of inferior hardness. In jewellery the word sapphire is used in a quasi-specific sense for all varieties except the red ruby; thus jewellers speak of white sapphire, yellow sapphire, green sapphire and even pink sapphire. Padparadschah, padparadscha or other corrupt form of the

Sinhalese word, *padmaragaya* (lotus-colour), has been introduced for the yellowish aurora-red gem material from Ceylon, but has become more commonly used for the synthetic material of similar tint. There is no real need for this fantastic term, and it may be hoped that it will pass into disuse.

Since in medieval times the finest gemstones reached Europe by way of the East and stones of similar colour were habitually confused, it was customary to apply the qualifying prefix, 'oriental', to the harder kinds; thus we find oriental-topaz used for the yellow, oriental-chrysolite for the yellowish-green, oriental-emerald for the green, oriental-aquamarine for the bluish-green, oriental-amethyst for the violet and oriental-hyacinth for the aurora-red variety of corundum. At the present day such terms are meaningless and confusing, and should no longer find currency.

Asterias or star-stones are blue (star-sapphire) or red (star-ruby, plate I, 14) corundum, which is so constituted that, when cabochon-cut, usually rather steeply, it shows in suitable illumination a six-rayed star. The explanation of this phenomenon is discussed below.

The word corundum comes through the French *corindon*, from an old Hindu word, *korund*, of unknown significance, and came to be applied, because the stones which were first introduced into Europe originated from India.

Sapphire is a word meaning blue, and, when first used, denoted lapis-lazuli and possibly other opaque minerals which were blue in colour. The ultimate derivation of the word is uncertain. It has reached us through the Latin form, *sapphirus*, of the Greek σάπφειρος. A similar word is found both in Hebrew and in Persian, but it does not appear to have been Semitic in origin. It is thought that the primitive source may have been Sanskrit. The term should properly be restricted to the blue variety of corundum, though there is no objection to the use of it, when suitably qualified, for other varieties. Such terms as 'Brazilian-sapphire', which is a blue tourmaline, and 'water-sapphire' or 'lynx-sapphire', which is cordierite, are wrong and should be dropped.

Ruby means red, and is derived from the Latin *ruber* (red) through the late form *rubinus*. In medieval times, when knowledge reached its nadir and little was generally known about the characters of gemstones, it was loosely used for all red stones, but was eventually restricted to the hardest of them, the red variety of corundum (the exceedingly rare red diamond was not known then). Any other use of the word, even the old-established term balas-ruby for the red spinel, is to be deprecated. All such terms as 'Cape-ruby' garnet) and similar place synonyms for garnet, 'Brazilian-ruby' (topaz) and 'Siberian-ruby' (tourmaline) are misleading and should not be used.

In composition corundum is alumina, oxide of aluminium, corresponding to the formula Al_2O_3, but it usually contains in addition small quantities of ferric iron, chromium and other metals. When pure, it is colourless; the splendid tints which are its glory have their origin in the minute traces of the other metals present. The long-held suspicion that chromium is the cause of the colour of ruby was confirmed by the success achieved by the use of chromium oxide as the tinctorial agent in the synthesis of this gemstone (p. 196), although it may be noted that in the synthetic stones a far higher percentage of chromic oxide is incorporated than has been revealed by chemical analysis in the natural stones. The variation in the tint of the latter may be explained by the presence, though in minute quantities, of other colouring agents, notably ferric oxide. The most highly-prized shade of red is the so-called pigeon's blood, one which is slightly inclined to purple. The depth of tint of the red stones varies considerably; when pale, they are termed pink sapphires, but they grade insensibly into rubies, and no sharp distinction can be drawn between them. That the blue colour of sapphire is caused by the presence of titanium is established by its use as the colouring material in the synthesis of sapphire. Chromic oxide is isomorphous with alumina and chromium may therefore be expected to fit harmoniously into the crystal structure. Trivalent titanium may also replace aluminium. It has been suggested that titanium is present in the form of $TiFeO_3$ (ilmenite), but the absorption spectrum of synthetic blue corundum (p. 112) shows no trace of iron. The yellow tint, which is not uncommon, is due to the presence of ferric oxide. Multi-coloured stones are common: blue and red zones sometimes alternate and give rise to an apparently purple or violet tint, and yellow and blue patches may occur in the same stone. In Nature perfectly colourless stones are far from common, a slight bluish tinge being noticeable; they are in little demand for jewellery, because they lack fire, and are consequently of little interest when cut. A sapphire and a ruby crystal, a faceted blue sapphire, a faceted yellow sapphire, and a figure of Buddha cut from a sapphire are shown on plate VIII, and a star-ruby appears on plate I; all of them are in natural colour.

Corundum belongs to the holosymmetric class of the trigonal system of crystal symmetry. The crystals (fig. 120 and plate VIII, 3 and 13) are mainly of two kinds: in the first, a large face (with possibly another parallell to it at the other end), which is often triangularly marked, belonging to the basal form *c* {0001}, is combined with six faces of the prism *m* $\{10\bar{1}0\}$

and the six faces, three above and three below, of the primitive rhombohedron $r\ \{10\bar{1}1\}$; and in the second, twelve faces, six above and six below, of the pyramid $v\ \{44\bar{8}3\}$, meeting in the girdle, are the most conspicuous, the other forms being either small or absent. The former habit is favoured by ruby, and the latter by sapphire and other varieties of corundum. Much corundum occurs in large, opaque and granular masses.

Since corundum belongs to the trigonal system, it is doubly refractive, and the birefraction is uniaxial in character, the direction of single refraction running parallel to the edges of the prism faces and at right angles to the basal faces. Owing to the comparative purity of the chemical composition the refractive indices are very constant; the ordinary index ranges from 1·768 to 1·778 and the extraordinary index from 1·760 to 1·770, the amount of double refraction remaining always the same, 0·008. Since the extraordinary is less than the ordinary index, the sign of the double refraction is negative. The colour-dispersion, that is, the difference between the refractive indices for the *B* and *G* lines of the solar spectrum, is 0·018; it is slightly higher for the ordinary than for the extraordinary index, but the difference is perceptible only in the fourth place of decimals. Owing to the smallness of the colour-dispersion, colourless corundum displays very little fire when cut. It is because of the small amount of colour-dispersion that a cut sapphire or ruby shows such a wide fringe of colour when tested on the refractometer in daylight. Since ruby and sapphire transmit mainly red and blue light respectively, which have different refractive indices, the cut stones may be slightly differently treated; experience has shown that the base of a

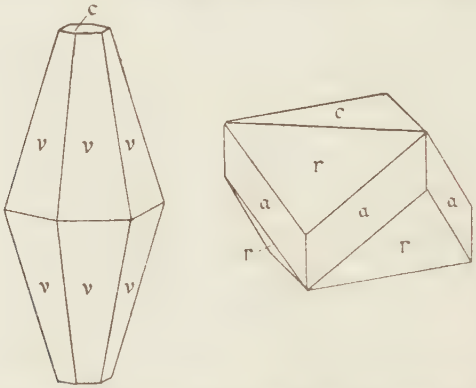

FIG. 120.—Corundum crystals: (1) sapphire, bipyramidal; (2) ruby, tabular parallel to basal pinacoid.

cut ruby may be left relatively thick without impairing the optical effect.

Both sapphire and ruby have marked and characteristic dichroism, the twin-colours shown by the former being deep blue (ordinary ray) and yellowish-blue (extraordinary ray), and by the latter deep purplish-red (ordinary ray) and pale yellowish-red (extraordinary ray). It is therefore a most important feature of their dichroic properties that the colour corresponding to the ordinary ray is fine and deep, whereas that corresponding to the extraordinary ray is pale and inferior in tint. Consequently, whenever possible, sapphires and rubies should be cut with the table facet parallel to the basal plane, that is at right angles to the crystallographic axis. The only exception is the rare instance of a stone so dark in colour that the ordinary ray is almost wholly absorbed, in which case the table facet should be nearly at right angles to the basal plane, in order to allow for the transmission of the extraordinary ray.

Yellow corundum shows distinct signs of dichroism, but by a variation more of the depth than of the shade of the colour; the phenomenon is faint compared with the dichroic effect characteristic of yellow chrysoberyl.

As is usually the case, the application of heat tends to lighten the colour of corundum; those of a pale-violet or yellow colour lose their tint altogether, and the deep-violet stones turn a lovely rose colour. Irradiation, on the other hand, tends to deepen the colour and even to develop it in a colourless stone; it may be inferred from this reaction that, as in window-glass, two or more colouring agents are present in an apparently colourless stone and their uneven response to the stimulus gives rise to a colour effect.

The lustre of corundum is vitreous. The best examples are perfectly clear and transparent, but frequently contain colloidal and other inclusions. When, as often happens, these are arranged parallel to the edges which the six prism faces make with the basal face, the effect is an arrangement of bundles of lines mutually inclined at angles of 60°. If such a stone be cabochon cut so that the axis of symmetry is at right angles to the original basal face, light impinging upon it is reflected from the interior in the form of a six-rayed star. Such stones are called asterias or star-stones (star-sapphire or star-ruby). Their appearance is very pleasing. Some stones from Siam possess a markedly fibrous or silky structure due to inclusions of titaniferous magnetite. Burma and Siam rubies are usually different in appearance. The rather duller tint of Siam stones is thought to be due to the presence of iron. Burma rubies contain slender oriented needles of rutile together with curved hollow pipes, whereas Siam rubies are devoid of such needles, but on the other hand they possess numerous hexagonal cavities or thin crystal plates arranged in parallel planes together with canals, containing bubbles and liquid inclusions.

The beauty of ruby, the effect which to no small degree sets it above all other red gemstones, is due to the characteristic fluorescent doublet near the red end of the visible spectrum. The fluorescence is stimulated by sunlight and ultra-violet rays generally, and, it should be noted, characterizes the synthetic material also. As might be anticipated, the red colour is due to the more or less complete absorption of the rest of the visible spectrum, and the blue of sapphire and the other shades shown by gem material result from the corresponding absorption. The absorption-spectra displayed have already been discussed (pp. 104, 107).

The specific gravity of corundum is likewise very constant, varying from 3·94 to 4·10 according to the extent and nature of the impurities present; in the gem material the range is somewhat smaller, the mean being 4·00, with a variation from it of 0·01. Sapphire and ruby therefore rank with almandine garnet and zircon as the densest of gemstones.

The following are the values of the physical constants determined for different varieties of corundum. The respective ranges for the extraordinary and ordinary refractive indices are for: white sapphire, 1·759 to 1·761, 1·768 to 1·769; Burma ruby, 1·760 to 1·769, 1·768 to 1·778; Siam ruby, 1·760 to 1·764, 1·768 to 1·772; sapphire, 1·760 to 1·762, 1·768 to 1·770; green sapphire, 1·762 to 1·770, 1·770 to 1·779. The birefringence is normally 0·008, but may rise to 0·009 for green sapphire. The corresponding values for the pure synthetic stones, which are colourless, are 1·760 and 1·768, agreeing with those of the natural white sapphire. The values of the specific gravity found are as follows, the corresponding weights in metric carats being given in brackets: Burma ruby, (35·000) 3·996; Burma deep-coloured ruby, (13·217) 3·997; Siam ruby, (8·970) 4·006; sapphire, (39·03) 3·994; Kashmir sapphire, (14·815) 3·994; Ceylon sapphire, (53·54) 3·996; Burma sapphire, (15·69) 4·002; Australian sapphire, (11·855) 4·001; Australian yellow sapphire, (28·168) 3·994. In the case of the following stones the values of the specific gravity and of the extraordinary and ordinary refractive indices are collated: white sapphire, 3·993—1·761, 1·769; Burma ruby, 3·996—?, 1·772; Ceylon ruby, 3·999—?, 1·772; Siam deep-coloured ruby, 3·999—1·768, 1·776; Ceylon yellow sapphire, 3·994—1·761, 1·769; Ceylon green sapphires, 3·999—1·765, 1·773, and 4·009—1·770 1·779.

Corundum stands alone as next to diamond the hardest of gemstones, and bears the symbol 9 on Mohs's scale of hardness. Though ranking next to diamond, it is a very poor second (p. 261), the difference in hardness between it and diamond being far greater than that between it and the softest of minerals.

Corundum has a parting parallel to the basal face and another, less common, parallel to the faces of the primary rhombohedron, both due to the effect of twinning. The difference between a parting and cleavage is that in the former case the stone can separate along certain definite planes only, whereas in the latter it can be split, as for instance in diamond, anywhere parallel to the cleavage plane.

As has been pointed out above, corundum, of whatever colour, cannot be cut at random if the best effect is to be achieved, and careful attention must be paid to the crystal symmetry, in order to use the dichroic property in the best way possible. Also in star-stones the base of the cabochon must be parallel to the basal face of the crystal. Considerable latitude is allowed in the forms given to the coloured transparent stones. At one time they were invariably step- or table-cut; but nowadays they may be brilliant-cut or be mixed-cut, that is, with a brilliant-cut crown and a step-cut base. The general shape will, of course, depend upon the purpose for which the stone is required; for instance, in a ring, a pendant or an ear-ring.

Besides its use for ornamental wear gem corundum has other important uses, on account of its hardness and toughness, as bearings for the moving parts of watches and instruments of precision generally, although for this purpose the synthetic material has largely replaced the natural stones, not so much because of its cheapness, but because the crystal orientation, which is an important factor, is more readily ascertained in the case of a boule. Both the opaque corundum and the impure kind, known as emery, are in general use for grinding and polishing softer stones, steel and other metal-work. The dull, nearly opaque, corundum from India, when ground for use as polishing material is known as adamantine-spar.

It is remarkable that, in spite of the successful synthesis of ruby, sapphire and other varieties of corundum, such material possesses hardly any commercial value. The natural stones, on the other hand, command high prices. Large rubies, being comparatively rare, are among the most costly of precious stones. Large sapphires, on the other hand, are more plentiful, and this fact is reflected in a much lower top price per carat. The yellow and other varieties are in little demand, and their prices are correspondingly low.

The historical sapphires and rubies in the British regalia and the

Edwardes ruby crystal in the British Museum (Natural History) have been described in a previous chapter. Mention should be made of three other specimens in the Museum collection. The first is a beautiful rose-cut sapphire, which was included in the Sir Hans Sloane[1] collection; octagonal in outline, measuring $\frac{3}{4}$ inch (19 mm.) in diameter, and weighing 31·5 carats, it is set with inlaid gold, rubies and emeralds in a quartz button. The second is an exquisitely carved figure of Buddha (plate VIII, 2) set on a gold pin, and the third, a large, though distorted, crystal of ruby from Burma, measuring $4\frac{3}{4}$ inches (12 cm.) in its widest diameter and weighing $1\frac{1}{2}$ lb. (690 grams). A fine cut stone, weighing about 102 carats, which is brilliant-cut above and step-cut below the girdle, is said to have been in the possession of a former Duke of Devonshire.

The former Russian regalia contains a magnificent sapphire, a beautiful cornflower-blue in colour, oval in shape (3·9 to 3·4 cm. in diameter, and 2·2 cm. in depth), and 260 carats in weight. The red stone, as large as a pigeon's egg, which was presented to the Empress Catherine II by King Gustavus Adolphus of Sweden in 1777 during a visit to St Petersburg, which was long reported to be a ruby, is a pink tourmaline of indifferent quality, 250 carats in weight. These stones are now in the Diamond Treasury at Moscow.

The collection in the Jardin des Plantes, Paris, contains two splendid rough sapphires: the one, of a brownish tint, known as the 'Rospoli' is quite flawless and weighs 135 carats, and the other is 2 inches (5 cm.) in length and $1\frac{1}{2}$ inches (3·8 cm.) in thickness.

A fine series is included in the J. Pierpont Morgan collection in the American Museum of Natural History, New York; among them may be mentioned a large sapphire, weighing 163 carats, and a yellow stone, weighing about 100 carats, both from Ceylon; a violet stone, weighing about 34 carats, from Siam; a golden-yellow stone, weighing 75·4 carats, and three magnificent star-stones, which are the largest known of their several kinds: the 'Edith Haggin de Long' star-ruby, measuring $1\frac{1}{2}$ inches (3·8 cm.) in length and 1 inch (2·5 cm.) across, and weighing 100 carats, from Burma; the 'Star of India' star-sapphire, weighing 563 carats, from Ceylon; and the 'Midnight Star' deep-purple star-sapphire, weighing 116 carats, also from Ceylon.

Large rubies are not very common and were far rarer in the old days, when such as were discovered were jealously hoarded by the rulers of Burma. Tavernier mentions that he saw some fine stones among the

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[1] Sir Hans Sloane, Bart., P.R.S. (1660–1753). The acquisition of his collections for the Nation led to the foundation of the British Museum in 1753.

treasures which were shown to him in India. In 1875, when the Burmese king was in need of money, two of the finest rubies which up till then had been seen in Europe were sold in London. The one, rich in colour, was originally cushion-shaped and weighed 37 carats; the other was a blunt drop in form and weighed 47 old carats. Both were cut in London, the former being reduced to $32\frac{5}{16}$ old carats (33 carats) and the latter to $38\frac{9}{16}$ old carats (39·6 carats), and were sold for £10,000 and £20,000 respectively. A colossal ruby, weighing 400 old carats, is said to have been found in Burma; it was broken into three pieces, of which two were cut and resulted in stones weighing 70 and 45 old carats respectively, and the third was sold uncut in Calcutta for 7 lacs of rupees (about £50,000). The finder of another large stone broke it into two parts, which after cutting weighed 98 and 74 old carats respectively; he attempted in vain to evade the royal acquisitiveness, by giving up the larger stone to the king and concealing the other. A fine stone, known by the formidable appellation of 'Gnaga Boh' (Dragon Lord), weighed 44 old carats in the rough and 20 old carats after cutting. After the mines were taken over by Burma Ruby Mines, several large stones were discovered. A beautiful ruby was found in the Tagoungnandaing Valley, and weighed $18\frac{1}{2}$ old carats in the rough and 11 old carats after cutting; perfectly clear and of splendid colour, it was sold for £7000. Another, weighing 77 old carats in the rough, was found in 1899, and was sold in India in 1904 for 4 lacs of rupees (about £30,000). A stone weighing 49 old carats, was discovered in 1887, and an enormous one, weighing as much as 304 old carats, in 1890.

Mention should be made of the 'Peace' ruby, weighing 42 carats, and a much finer stone, weighing 27 carats, both of which were discovered in 1919, being sold when cut for £20,000 and £27,000 respectively; and of another large stone, weighing 96 carats, which was discovered in 1929. Since 1929 few large rubies have been mined. A fine ruby, of the coveted pigeon's-blood hue, which weighed 20 carats in the rough and $7\frac{1}{2}$ carats after cutting, was found in 1933. Comparatively uncommon as sapphires are in the Burma mines, a faultless stone, weighing as much as $79\frac{1}{2}$ carats, has been discovered there. By far the largest sapphire that has been recorded is the one seen by the British Mission to the King of Ava, Burma, in 1827; the weight is said to have been 951 carats.

As might perhaps be anticipated, opaque or only sporadically translucent corundum reaches much larger sizes than the gem material does. A large hexagonal prism, measuring 10 inches (25 cm.) in height and 7 inches (18 cm.) in width and weighing 34 lb. (15 kg.), from North Carolina, is exhibited in the Mineral Gallery of the British Museum

(Natural History). A very much larger mass, pyramidal in form, measuring 2 feet 3 inches (68 cm.) in width and weighing 3 cwt. (152 kg.), from the northern Transvaal, is in the Geological Survey Museum, Pretoria.

The synthesis of sapphire and ruby and the discrimination of such material, when cut, from natural stones have been discussed in a previous chapter. Ruby might be confused with spinel or almandine garnet. Both the last are single refractive, so that the unmistakable dichroism of ruby will easily distinguish it; and other useful diagnostic features are the refractive indices, high specific gravity and the characteristic bright lines in the absorption-spectrum. Sapphire also is readily distinguished from other blue stones by its dichroism, and the other diagnostic features resemble those for ruby. In the case of the other colours reliance should be placed upon the refractive indices and the specific gravity. Paste imitations are detected by their softness, single refraction, refractive index and larger colour-dispersion.

Corundum occurs as the original constituent of various igneous rocks, as veins and segregations, and as the result of contact-metamorphism. The finest gem material is found as crystals in crystalline limestone or as pebbles in the alluvial deposits that have been formed from the disintegration of such rocks.

The world's supply of fine rubies is drawn almost entirely from the famous ruby mines near Mogok, situated about 90 miles (145 km.) in a north-easterly direction from Mandalay in Upper Burma and at an elevation of about 4000 feet (1200 m.) above sea-level. It is from this district that the stones of the coveted carmine-red, the so-called 'pigeon's blood', colour are obtained. The ruby occurs in lenticular bands of limestone in association with spinel (of very similar colour and appearance), tourmaline (usually black, but occasionally blue), sapphire (of various shades, occasionally blue), quartz, beryl, garnet, chrysoberyl, topaz, olivine, scapolite, apatite and fibrolite (sometimes in gem quality). Stones are occasionally found in the limestone on the sides of the hills, though not in paying quantity. By far the largest amount occurs in the alluvial deposits, both gravel and clay, in the river-beds; the ruby ground is locally known as 'byon'. The stones are as a rule quite small, averaging only about four to the carat.

Before the British annexation of the country in 1885 the mines were a monopoly of the Burmese sovereigns, and were worked solely under royal licence. They are known to be of great antiquity, but otherwise their early history is a mystery. It is said that an astute king secured the priceless territory in 1597 from the neighbouring Chinese Shans in exchange for a small and unimportant town on the Irrawaddy; if that be so, he struck an excellent bargain. The mines were allotted to licensed miners, *twin-tsas* (eaters of the mine) as they were called in the language of the country, who not only paid for the privilege, but were also compelled to hand over to the king all stones above a certain weight. As might be anticipated, this injunction caused considerable trouble, and the royal monopolists constantly suspected the miners of evading the regulation by breaking up stones of exceptional size; judging from subsequent experience, it is probable that large stones were in reality seldom found.

After 1887 the mines were worked by the Burma Ruby Mines, an English company. Its career was very chequered. It had to face increasing cost of production with the exhaustion of the richest fields, the at first severe competition of the synthetic ruby, and finally the financial difficulties that were the aftermath of the War, with the result that operations were closed down in 1931. The mines are, however, still being primitively worked by the natives.

While the Burma ruby is famed throughout the world as the finest of its kind the Burma sapphire has been ignominiously, but unjustly, dismissed as of poor quality. In actual fact nowhere in the world are such superb sapphires produced as in Burma. In view, however, of the disrepute into which the Burma sapphire has fallen its commercial value is correspondingly lower and shrewd dealers are apt to dispose of their wares in the neighbouring state, Siam, or a little farther afield, in the island of Ceylon, in both of which regions the sapphire is regarded as of the highest class. Yet it is not unlikely that its reputation has been greatly enhanced by material from Burma.

The sapphire crystals are of the pyramidal habit generally characteristic of the blue variety of corundum. The finest colour is a magnificent royal-blue, which is sometimes accompanied by a velvety lustre, due to inclusions. The colossal stone, known as the 'Gem of the Jungle', which was found in 1929 on the surface just below the grass, weighed as much as 958 carats in the rough. It was far too large to be cut into a single stone, and from it its purchaser, Mr Albert Ramsay, obtained as many as nine superb sapphires, weighing respectively 66·5, 20·25, 20, 13·11, 12·25, 11·33, 11·11, 5·50 and 4·33 metric carats. Beautiful stones, a deep cornflower-blue in colour and also with a velvety lustre, are also found, as well as many, paler in colour and less lustrous, which in less favoured regions would be considered of remarkable quality. Excellent star-sapphires too are not uncommon, and the less desired varieties—colourless, yellow and purple—are to be met with, but the green corundum is entirely absent.

The principal locality begins about 8 miles (13 km.) west of Mogok and higher in altitude by about 1000 feet (300 m.), and save for a small barren patch continues for about 6 miles (10 km.) and then swings to the north-east for a similar distance, rising all the time. Some 3 miles (5 km.) farther north near Bernardmyo is another field where magnificent stones have been found, with, however, some of a peculiar indigo colour, which become either very dark or greenish in artificial light.

Sapphires of good quality are found either in the valley or the hillside deposits and not in the crevices of the hills. Although they occur in the same deposit as rubies in the Mogok Valley, the rock in which they are contained is an igneous one and not a limestone.

Good rubies, mostly darker in colour than the Burmese stones, are found in considerable quantity near Bangkok in Siam, Chantabun being the centre of the trade, where, just as in Burma, they are intimately associated with the red spinel. Because of the difference in tint and the consequent difference in price, jewellers draw a distinction between Burma and Siam rubies; but that, of course, does not signify any specific difference between them. Siam is, however, most distinguished as the original home of splendid sapphires, though many of the stones sold as Siamese have come either from Burma on the west or from territory on the east which has not always been politically part of Siam. The district of Bo Pie Rin in Battambang (Cambodia) has produced a large proportion of the world's supply of sapphires. In the Hills of Precious Stones, such being the meaning of the native name for the locality, a number of green corundums have been found. Many 'Siamese' sapphires have come from the Phailin mines, Cambodia, in what was once Siamese territory but for long formed part of French Indo-China; some ruby and zircon also occur here. Siam also produces brown stones, characterized by a peculiar silkiness of structure.

The conditions in Ceylon are markedly different from those in Burma; in the former, sapphires are plentiful and held in high esteem, whereas, as we have already noted, in Burma rubies are pre-eminent and sapphires are, though undeservedly, under a cloud. Sapphires occur in Ceylon in great variety; blue stones, exceptional both in colour and in size, have been found, some, indeed, so enormous that it was not expedient to cut them as single stones, but generally they are pale in tint and are often parti-coloured. It is probable that many of the good quality sapphires sold in the island were not mined there. Rubies, too, are usually pale in tint; sometimes the colour is too purple and is then improved by heating. Colourless and yellow stones are common. All yellow stones are locally called topaz, and the deep-yellow sapphire is distinguished by the name 'king-topaz' and the paler-tinted kind by that of 'oriental-topaz', both undesirable names. The rarer green variety is sometimes found. Star-sapphires also are not uncommon.

The gravels, which yield the sapphires and rubies, contain in addition all the other important species of gemstones with the exception of diamond and the emerald variety of beryl, and in no other part of the world is such an immense variety of gem material brought together within so small an area. The species which have been found with corundum are chrysoberyl, spinel, zircon, topaz, garnet, tourmaline, quartz, orthoclase (moonstone), sphene, cordierite, fibrolite, andalusite, diopside, kornerupine and apatite; an associated mineral is rutile. The stones were formed in various rocks, such as schists, gneisses and crystalline dolomitic limestones, but upon their weathering were concentrated in the gem-bearing deposits, locally known as 'illam,' which were formed in the present or former beds of various streams. The deposits are in the form of beds, patches or pockets, and may occur at any depth down to the actual floor of the valley, about 120 feet (36 m.) down, though usually not far below the surface of the ground. The gravel is mostly composed of white quartz pebbles with ferruginous concretions, sand and organic matter.

The gem district lies in the south-western part of Ceylon with Ratnapura (City of Gems) as its centre, and extends up to the south coast. Mining is wholly in Sinhalese hands, and is carried on by simple methods; the gravel is carried to a convenient stream in baskets, in which it is there concentrated, and the gem material is picked out by hand.

Beautiful sapphires occur in various parts of India, but especially in the Zanskar range of the north-western Himalayas in Kashmir, where they are found in a pegmatite vein in association with tourmaline, garnet, kyanite and euclase.

Sapphires of good quality, which have the merit of retaining their colour in artificial light, have emanated from Montana in the United States. Most important is the Yogo deposit in Judith Basin County, 85 miles (135 km.) east of Helena, where the gem material is found in a much weathered, nearly vertical dyke, which is about 10 to 20 feet (3 to 6 m.) in thickness. The stones were never very large, and seldom ran much over 10 carats. In colour they ranged through various shades of blue from light to dark, some being of the prized cornflower tint; red and violet stones also were found. Other localities are on the Missouri River about 12 miles (19 km.) east of Helena. Here the commonest colour is a bluish-green, generally pale, but blue, green, yellow and occasionally red stones also are found. With them are associated gold, colourless topaz, kyanite and a beautiful red garnet, which occurs in granular form and is often mistaken for ruby. Rubies, of moderate quality, have been found in the sands of Cowee Creek, about 6 miles (10 km.) north of Franklin, Macon County, North Carolina.

The prolific gem district extending over about 20 square miles near Anakie, in Queensland, has supplied examples of every variety of corundum except the red kind, ruby; blue, green, yellow, purple and parti-coloured stones, and star-stones have been plentiful. Sapphire is widespread in New South Wales, but only in the Inverell district is it suitable for gem purposes. Farther south, in Victoria, leaf-green corundum has been found. On the whole the Australian blue sapphire is too dark in colour to be of much value.

A few minor localities for corundum of gem quality may be briefly mentioned. In Southern Rhodesia small rubies and sapphires occur with chrysoberyl and topaz in the gem gravels near the Somabula Forest. In Tanganyika small waterworn crystals of ruby have provided material for cutting; larger crystals of good colour are often opaque. Ruby has been found with spinel and garnet in Afghanistan, to the north of the lapis-lazuli mines and near Jagdalak, to the east of Kabul. Sapphire and ruby, though not of good quality, have been reported from the Yunnan Province of China, Manchuria, Congo, Angola, Madagascar, Norway and Colombia. Sapphires of gem quality were at one time found in Bohemia.

XXIII

BERYL

The species which is considered in this chapter includes the varieties emerald and aquamarine, as well as what jewellers ordinarily understand by beryl. It has many incontestable claims upon the attention of all lovers of the beautiful in gemstones. The peerless emerald, which in its verdant beauty recalls the exquisite lawns that grace the courts and quadrangles of our older seats of learning, has long ranked among the most costly of jewels. Even Pliny ranked the emerald third, although he knew only the comparatively inferior stones from Egypt and possibly from the Ural Mountains; he says (in English translation): 'The third rank, for many reasons, has been given to the smaragdus. Indeed there is no stone the colour of which is more delightful to the eye.' [1] Its sister stone, the lovely aquamarine, which seems to have come direct from some mermaid's treasure-house in the depths of a summer sea, has charms not to be denied. Emeralds are favourite ring-stones, and would no doubt be equally popular for larger pieces of jewellery if it were not for their high cost. Nothing could be more attractive for the central stone of a pendant than a choice aquamarine, of deep bluish-green hue.

In mineralogy the name beryl is applied to the whole species, emerald being the grass-green and aquamarine the sea-green variety; but in jewellery it is used in a narrow sense for paler shades and generally for colours other than green, so that it is customary to speak of yellow beryl or pink beryl. In modern times there has been further delimitation, morganite being used for the rose-red and heliodor for the golden-yellow variety.

The name of the species has come down to us through the Latin *beryllus* from the Greek *βήρυλλος*, an ancient word, the meaning of which has been lost in the mists of time. It has probably from the beginning denoted the same species, at least in part, as that now

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[1] 'Tertia auctoritas smaragdis perhibetur pluribus de causis. Nullius coloris aspectus jucundior est.' Loc. cit., book 37, ch. 5. According to Pliny diamond was first and pearl second.

understood by the name. Emerald is derived from a Persian word, which appears in Greek as σμάραγδος, and has reached us through such altered forms of the Latin *smaragdus* as *esmeraude*, *emeraude* and *esmeralde*; the present form did not make its appearance in English until the sixteenth century. It has apparently always been used for a mineral of green colour, but perhaps originally, instead of the mineral being transparent, it may have been one that is opaque, though brightly coloured, such as chrysocolla; the name was not applied to the grass-green beryl until the discovery of such stones in Upper Egypt. The name aquamarine was suggested by Pliny's happy description of this variety of beryl, although it was never used by him: 'The most esteemed beryls are those which in colour resemble the pure green of the sea.' [1] Although the fact that emerald and beryl belong to the same mineral species was not definitely established until early in the nineteenth century, it was suspected in Pliny's time; for he says: 'Beryls, it is thought, are of the same nature as the smaragdus, or at least closely analogous.' [2] The variety morganite was named after the banker, John Pierpont Morgan, whose collection of gemstones is now in the American Museum of Natural History, New York. Rose-coloured beryl, as well as the colourless kind, from Madagascar, was called vorobyevite (or worobewite) by A. Lacroix, but the name had previously been given by V. I. Vernadsky to colourless beryl from the Urals in memory of V. I. Vorobyev (1875–1906). The name heliodor was applied to the yellow beryls discovered in South-West Africa in 1910, and is derived from the Greek words ἥλιος (sun) and δῶρον (gift).

Beryl, to use the name by which the species is known to science, is essentially a beryllium-aluminium silicate corresponding to the formula $Be_3Al_2(SiO_3)_6$. Analyses frequently show small amounts of the alkali metals and also of helium; it is believed that atoms of these elements do not participate in the binding of the structural framework of the beryl containing them and that they are held in the channels which run through the structure parallel to the hexagonal axis. Small amounts of chromium and ferric iron may replace aluminium in the usual manner. From 1 to 2 per cent of water has been found in emerald. The element beryllium was, as its name suggests, first discovered in a specimen of this species, the discovery being made in 1798 by the chemist Vauquelin [3]; it is also known as glucinum in allusion to the sweet taste of its salts.[4]

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[1] 'Probatissimi sunt ex iis qui viriditatem puri maris imitantur.' Loc. cit., book 37, ch. 5.

[2] 'Eamdem multis naturam aut certe similem habere berylli videntur.' Loc. cit., book 37, ch. 5.

[3] Louis Nicolas Vauquelin (1763–1829).

[4] Glucinum is derived from the Greek word, γλυκύς (sweet).

When pure, beryl is colourless, but owing to the almost invariable presence of impurities it is coloured, the various tints being grass-green (emerald), which is so peculiar to this variety that the particular shade is in consequence known as emerald-green, sea-green to blue (aquamarine), rose-red (morganite) and yellow. The colour of emerald is usually due to the presence of a small percentage of chromium; V. M. Goldschmidt has claimed that trivalent vanadium can function in place of the chromium. The shades of aquamarine, varying from bluish to yellowish-green have been variously ascribed to the presence of ferric iron or of scandium, or to a structural defect; the blushing tint of morganite may be caused by the presence of lithium, and as usual ferric iron is responsible for the colour of yellow beryl; heliodor contains a small percentage of uranium and is therefore radioactive. Cut examples and crystals of emerald, aquamarine, heliodor, blue beryl and golden beryl are shown in natural colour on plate VIII.

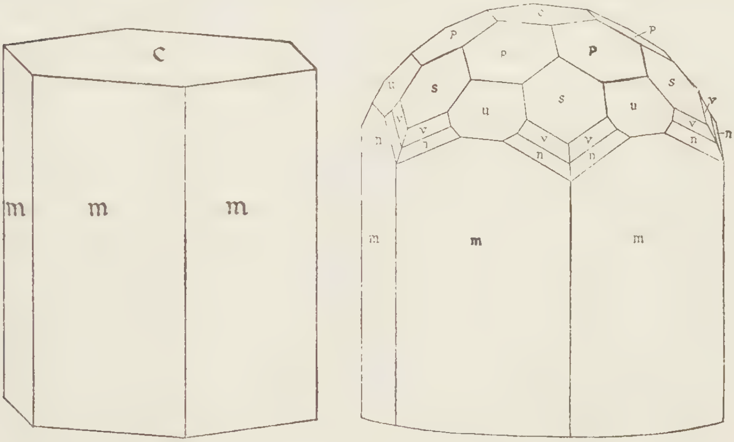

FIG. 121.—Beryl crystals: (1) emerald, (2) aquamarine.

Beryl crystallizes in the hexagonal system, and the crystals possess all the symmetry possible in that system. The normal habit of the crystals comprises a prism of six faces, which in the case of emerald (fig. 121) is invariably terminated, if the crystal be complete, by a basal face that is at right angles to the prism-edge; in the case of aquamarine the crystals have in addition a number of small inclined faces (fig. 121 (2)), and stones from both Russia and Brazil often taper owing to the effects of corrosion.

The character of the crystal symmetry necessarily means that the double refraction is uniaxial in character, and, since the extraordinary is less than the ordinary refractive index, it is negative in sign. The values of the extraordinary and ordinary indices vary rather widely, ranging between 1·560 and 1·590, and between 1·565 and 1·599 respectively, the birefringence increasing with the refractive index from 0·005 to 0·009. The dichroism is very faint, except in the Colombian emerald, in which it is distinct, the twin-colours being yellowish-green and bluish-green. The colour-dispersion is low, amounting to 0·014 for the *B–G* interval.

The specific gravity also has a considerable variation, the range being from 2·67 to 2·90. Beryl is thus perceptibly denser than quartz, and if a beryl and a quartz be floating in a tube containing a suitably diffused heavy liquid, the former will always be appreciably below the other (fig. 74).

The values of the extraordinary and the ordinary refractive indices for the Colombian emerald range between 1·565 and 1·570 and between 1·570 and 1·575 respectively, but for the Siberian emerald the upper limits are rather higher, namely, 1·574 and 1·580, the birefringence at the same time reaching 0·006; for the pale emerald from Brazil they are 1·566 and 1·571. The South African emerald has perceptibly higher refractive indices, the values ranging between 1·580 and 1·586 and between 1·587 and 1·593, the birefringence also being higher, namely 0·007. For aquamarine the values range between 1·570 and 1·580 and between 1·575 and 1·586, the birefringence increasing with the refractive index from 0·005 to 0·006, and for morganite they range between 1·580 and 1·590 and between 1·588 and 1·599, the birefringence being the highest of any variety, namely 0·008 to 0·009. The yellow beryl has the values 1·568 and 1·573. It may be noted that synthetic emerald has the values 1·561 and 1·564; its birefringence varies between 0·001 and 0·004, and is therefore perceptibly lower than for any natural beryl (p. 205). The values for the specific gravity vary in a relatively similar manner. Colombian and Siberian emerald have values ranging from 2·70 and 2·72, but being mostly about 2·712. The Brazilian pale emerald is lighter, ranging from 2·67 to 2·70; the South African emerald, on the other hand, is denser, its range being 2·72 to 2·77, but most values being near 2·75. Aquamarine and yellow beryl have values between 2·68 and 2·70. The Brazilian green beryl is denser, about 2·80, and the values for morganite are the highest for any variety, the range being from 2·72 to 2·90, most of them being about 2·82; these high values are due to the presence of the alkali metals, caesium and rubidium. The absorption-spectrum is described on p. 106. Synthetic emerald is distinguished from natural beryl by its low specific gravity, about 2·66.

The hardness varies from 7½ to 8, emerald being a little softer than the other varieties. There is an indistinct cleavage parallel to the basal face; but like most gemstones beryl is very brittle, and can easily be fractured. Stones rendered cloudy by fissures are termed 'mossy'. When heated before the blowpipe, beryl is fusible with difficulty; it resists the attack of hydrofluoric acid as well as of ordinary acids.

Emeralds are usually step-cut, unless intended for rings, in which case they are often brilliant-cut; Indian lapidaries usually favour the cabochon form. Aquamarines are often mixed-cut. In general, there is no rigid rule and the form of cutting selected will depend on the purpose for which the stone is required.

Opaque beryl, which is not suitable for jewellery purposes, is the principal ore of the metal beryllium, which is used in the production of special alloys with copper mainly, and also with iron and nickel.

Emeralds, unlike some stones green in colour, retain their purity of tint in artificial light; in fact, to quote (in English translation) the words of Pliny: 'Neither sunshine, shade nor artificial light effects any change in their appearance.' [1] Many are the superstitions that have been fastened on to it. Thus, it was supposed to be beneficial to the eyes according to what Pliny says: 'And then, besides, of all the precious stones, this is the only one that feeds the sight without satiating it. Even when the vision has been fatigued with intently viewing other objects, it is refreshed by being turned upon this stone.' [2] Although we cannot go the whole way with Pliny, from common experience we know the restful effect of a green light upon the eyes. There was an old tradition in the East that emeralds had a fatal influence upon the eyesight of serpents; it appears in the following lines:

> 'Blinded like serpents when they gaze
> Upon the emerald's virgin blaze.' [3]

The Emperor Nero (p. 154) appears to have found an emerald crystal useful in enabling him to see the gladiatorial combats more distinctly; whether it was used as a lens or a mirror is uncertain.

Aquamarines, particularly if of a deep bluish-green colour, are very

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[1] 'Non sole mutati, non umbra, non lucernis.' Loc. cit., book 37, ch. 5.

[2] 'Praeterea soli gemmarum contuitu oculos implent, nec satiant. Quin et ab intentione alia obscurata, aspectu smaragdi recreatur acies.' Loc. cit., book 37, ch. 5.

[3] Thomas Moore (1779–1852), *Lalla Rookh, The Fire Worshippers.*

beautiful, and are popular stones for pendants and ear-rings, and, indeed, for all purposes for which a comparatively large bluish- or yellowish-green stone is desired. Good blue aquamarines are mostly heat-treated stones. All the varieties of beryl share with emerald the merit of remaining unaltered in tint in artificial light.

As has been shown in a previous chapter, emerald ranks with diamond and ruby as being the most precious of stones. So consistently is material of the true grass-green hue badly flawed that a cut stone, of good colour and free from flaws, which was more than 5 or 6 carats in weight, would command an altogether special price, beyond the reach of all except the privileged few that have purses deep enough. The immediate and apparently anomalous result of the rise in the value of high-class emeralds at the beginning of the century was to make these rare stones more plentiful, because the high prices prevailing tempted owners of old jewellery to dispose of their emeralds. On the other hand, pale emeralds are worth only a nominal sum.

Aquamarine and the other varieties of beryl are much less rare than emerald, and, since they attain to much greater size, far larger stones are readily obtainable; prices are therefore moderate.

The famous 'Devonshire' emerald crystal has been described in an earlier chapter (p. 251). A finer, though much smaller, crystal of emerald, but of even better colour, which weighs 161 carats and measures $1\frac{1}{8}$ inches (28 mm.) in its widest cross-diameter and about the same in length, was acquired with the Allan-Greg collection (p. 252) by the Trustees of the British Museum, and is exhibited in the Mineral Gallery of the British Museum (Natural History). A small, but perfect and flawless, step-cut emerald, set in gold, is on view in the same Gallery; it is depicted in natural size on plate VIII. Among the other exhibited cut stones are two which exemplify the considerable size to which the varieties of beryl other than emerald can attain and yet remain clear and transparent. The one is a large aquamarine from Russia; step-cut and oval in contour, it is a beautiful sea-green in colour, flawless, and weighs 879·5 metric carats. The other is a pink beryl from Madagascar; step-cut and square in contour with rounded corners, it is a lovely rose-pink in colour, flawless, and weighs 598·7 metric carats. The old Russian regalia contained a superb, step-cut emerald, weighing 135·25 metric carats and measuring 36 mm. in length and 32·5 mm. in width (about $1\frac{1}{2}$ by $1\frac{1}{4}$ inches) at the girdle and 60 mm. ($2\frac{1}{3}$ inches) in depth. The stone, a deep green in colour with a slight bluish tinge, and almost flawless, is beautifully mounted. It is now in the Diamond Treasury at Moscow, and with it are other emeralds: a large, flawed, Russian stone, weighing about 245 carats, three cabochon-cut Colombian stones, weighing approximately 154, 65 and 24 carats, three fine table-cut stones, weighing 42, 41·5 and 40 carats, the last of which bears a Persian inscription.

The successful synthesis of emerald is no novelty, but it is only in recent years that stones large enough for cutting have appeared under the names 'igmerald' and 'Chatham' emerald. By careful determination of their physical properties, especially the optical characters, they may usually be distinguished from the corresponding natural stones, and many are recognizable by certain characteristic internal markings (p. 205).

The beryl glass obtained by the fusion of powdered natural stones is easily distinguished by its lower refractive index, and glass imitations have different refractive indices.

The colour of emeralds is so characteristic and peculiar that the experienced eye has usually little difficulty in distinguishing them from other green stones or from paste; a test with the Chelsea filter may be useful (p. 94), since most genuine stones appear through it red or pinkish, whereas imitations remain perceptibly greenish. The other varieties of beryl do not stand out so clearly; thus blue aquamarines may be confused with blue topazes, and pink beryls (morganites) with the pink topazes produced by heat, and yellow beryls resemble the yellow stones provided by other species, such as quartz, topaz and tourmaline. Beryl may readily be distinguished from these other gemstones by a determination of either its refractive indices or its specific gravity (p. 129).

Beryl occurs in pegmatites as an accessory mineral and also in various kinds of metamorphic rocks. Emerald in South America is found in calcite veins traversing shales of Cretaceous age.

In all probability the whole of the emeralds known in ancient times came from the so-called Cleopatra mines in Upper Egypt. For some reason they were abandoned, and their position was so completely lost that it was maintained by many writers that emeralds had never been found in Egypt at all, but had come from America by way of the East. All doubts were set at rest by the rediscovery of the mines by F. Cailliaud in 1818, who had been sent by the Viceroy of Egypt to search for them. They were, however, not much worked, and after a few years were closed again, and were reopened at the end of the century, but only for a short time and were then closed again, the fact being that the product cannot compare with the South American material. The principal mines are at Gebel Zubara and at Gebel Sikait in northern Etbai, about 10 miles (16 km.) apart and distant about 15 miles (24 km.) from the Red Sea, lying in the range of mountains that run for a long distance parallel to the west coast of the Red Sea and rise to over 1800 feet (550 m.) above sea-level. There are numerous signs of considerable, but primitive, workings at distinct periods. Both emeralds and beryls are found in micaceous and talcose schists. The emeralds are not of very good quality, being cloudy and rather light in colour.

Emeralds of much finer quality than those from Egypt have been found in a dark mica-schist, together with other beryllium minerals, chrysoberyl and phenakite, and also topaz and tourmaline, on the Asiatic side of the Ural Mountains, near the Takovaya River, which flows into the Bolshoi Reft River, one of the larger tributaries of the Pyschma River, about 50 miles (80 km.) east of Sverdlovsk (formerly Ekaterinburg), a town which is chiefly concerned with the mining and cutting of gemstones. The mine was accidentally discovered by a peasant, who noticed a few green stones at the foot of an uprooted tree in 1830. Two years later the mine was regularly worked, and remained open for twenty years, when it was closed. Owing to the high prices commanded by emeralds the mine was opened again early in the present century, and has been worked intermittently since then. Very large crystals have been produced here, but in colour they are much inferior to the South American stones; small Siberian emeralds, on the other hand, are of better colour than small South American emeralds, the latter being not so deep in tint.

None of the emeralds from either Egypt or Russia can compare in perfection of colour with the beautiful stones which have come from South America. At the time when the Spaniards grimly conquered Peru and ruthlessly despoiled the country of the treasures which could be carried away, immense numbers of emeralds—some of almost incredible size—were poured into Spain, and eventually found their way to other parts of Europe. These stones were known as Spanish or Peruvian emeralds, but in all probability none of them was actually mined in Peru. Perhaps the most extraordinary were the five choice stones which Hernando Cortes (1485–1547) presented to his bride, the niece of the Duke de Bejar, thereby mortally offending Queen Isabella of Spain, who had desired them for herself, and which were lost in 1541 when Cortes was shipwrecked on his disastrous voyage to assist Charles V, Emperor of Germany and King of Spain, at the siege of Algiers, the stronghold of the Mediterranean pirates. All five stones had been worked to divers fantastic shapes. One was cut like a bell with a fine pearl for a tongue, and bore on the rim in Spanish, 'Blessed is he who created thee.' A second was shaped like a rose, and a third like a horn. A fourth was fashioned like a fish, with eyes of gold. The fifth, which was the most valuable and the most remarkable of all, was hollowed out into the form of a cup, and had a foot of gold; its rim, which was formed of the same precious metal, was engraved with the words, 'Inter natos mulierum non surrexit major.' As soon as the Spaniards had seized nearly all the emeralds that the native inhabitants had amassed for use in their temples or for personal adornment, they devoted their attention to searching for the source of these marvels of nature, and eventually in 1558 they lighted by accident upon the mines in what is now the United States of Colombia, which have been worked almost continuously since that time. It is, however, probable that not all the mines worked by the original native inhabitants have been discovered; for, as soon as the inhabitants had experienced the gross injustice of their treatment at the hands of the Spaniards, and had realized the greed which prompted their action, they persistently refused to betray the position of the mines, and the prodigal growth of the vegetation in that region would have speedily obliterated every trace of the workings.

The present mines are situated near the village of Muzo, about 75 miles (120 km.) north-north-west of Bogotá, the capital of Colombia. The emeralds occur, in association with quartz, dolomite, and pyrites, in calcite veins in a bituminous limestone of Cretaceous age. The Spaniards formerly worked the mines by driving adits through the barren rock on the hillsides to the gem-bearing veins, but at the present day the open cut method of working is employed. A plentiful supply of water is available, which is accumulated in reservoirs and allowed at the proper time to sweep the debris of barren rock away into the Rio Minero, leaving the rock containing the emeralds exposed. Stones, of good quality, which are suited for cutting, are locally known as canutillos, inferior stones, coarse or ill-shaped, being called morallons. The crystals occur attached to the limestone, and are therefore never found doubly terminated; the habit is very simple, merely a prism with six faces and a basal face at right angles to them. They are so invariably flawed that a flawless emerald has passed into proverb as unattainable perfection. Owing to economic and other difficulties the Muzo mines have only been worked intermittently. Emerald has been worked also at Coscuez, 15 km. north-east of the Muzo mines, and at Chivor near Somondoco, 100 km. east-north-east of Bogotá.

Small emeralds, of superbly rich colour, were discovered in 1956 in schist adjacent to pegmatite dykes at Sandawana, 30 miles south of Belingwe, Southern Rhodesia.

Rather pale emeralds have come from Brazil. They were discovered in 1913 at Bom Jesus dos Meiras in Bahia in association with quartz and calcite in cavities in an altered marble. The habit is hexagonal prismatic and the crystals are typically flawed. The method of mining has been primitive, and the yield small.

In India, beryl crystals of a rich green colour have been found in bands of biotite-schist enclosed in hornblende-schist at Kaliguman, Mewar, Rajputana.

The only source of emeralds in Europe has been the Habachtal in the Salzburg Alps. Here simple prismatic crystals of beryl occur in a biotite schist and since the Middle Ages there has been a sporadic output of well-coloured emeralds.

The varieties of beryl other than emerald are not only more plentiful and more widely distributed, but they also occur in crystals or masses which are much larger and more uniformly transparent. The splendid six-sided columns which have been discovered in various parts of Siberia are among the most striking specimens in any large mineral collection. The neighbourhood of Sverdlovsk (Ekaterinburg) in the Urals is prolific in varieties of aquamarine; especially at Mursinka have fine stones been found, in association with topaz, amethyst and schorl (black tourmaline). Good stones also occur in conjunction with topaz at Miask in the Government of Orenburg. It has been found in the gold-washings of the Sanarka River, in the southern Urals, but the stones are not fitted for service as gems. Magnificent blue, green and yellow beryls are associated with topaz and smoky quartz in the granite of the Adun–Chalon range of mountains in the Nerchinsk district of Transbaikalia. Stones have also been found near the Urulga River in Siberia.

Most of the larger aquamarines, which have come into the market for some years past, have originated in Brazil. The most abundant source is Minas Gerais, which supplies in the utmost profusion clear, transparent stones, of pleasing colour and in various shades of blue, green and yellow, including the golden-yellow one to which the name heliodor has been given. The principal localities are on the Jequitinhonha River near Minas Novas and farther east near Theophilo Ottoni, especially at Marambaia on the Mucury River, which has yielded blue stones of exceptional quality. It was at this last locality that what is probably the largest and finest aquamarine crystal known was found on 28 March 1910 at a depth of 15 feet (5 m.) in a pegmatite vein. The crystal was a greenish-blue in colour and its form was a slightly irregular hexagonal prism with a face at one end, the other being broken; it measured 19 inches (48·3 cm.) lengthwise and 16 inches (41 cm.) across, and weighed 243 lb. (110·2 kg.); and so perfect was its transparency that it could be seen through from end to end. The crystal was conveyed to the city of Bahia, and was reported to have been sold for $25,000 (about £5000). More recently a superb many-faced crystal of gem quality has been found; it measured 8¾ inches (22 cm.) in height and 5½ inches (14 cm.) in width, and weighed 12 lb. (5·4 kg.).

Madagascar has produced splendid stones, of perfect rose-red tint and of the finest gem quality, which not infrequently attain to sizes large enough to yield on cutting stones of more than 500 carats in weight (p. 308); this is the variety to which the name morganite has been given. In addition, beryls of almost every variety except the emerald are found, the commoner specimens being colourless, yellow, blue or green. Beryl is widely distributed in the island.

Aquamarines of many tints abound in several localities in the United States, among the principal ones being Stoneham in Maine, Haddam in Connecticut and Pala and Mesa Grande in San Diego County, California. California is notable for the numerous stones of varying depth of salmon-pink that have been found there. On the whole they are paler in tint than the stones from Madagascar, and seldom attain to the true rose-red colour of morganite; that they do occasionally turn up is proved by the magnificent, rose-red crystal from California, weighing nearly 9 lb. (4 kg.) and measuring about 11 inches (27 cm.) in its greatest length, which is exhibited in the Mineral Gallery of the British Museum (Natural History).

Bluish-green beryl, varying in tint from almost colourless to an emerald-green, occurs with cassiterite (tinstone) and topaz in a pegmatite dyke about 9 miles (14·5 km.) north-east of Emmaville in New South Wales. Similar material has been found in greater profusion in mica-schist and pegmatite dykes some 40 miles (64 km.) north-west of Cue in Western Australia. There are several other minor localities in Australia, where beryl is found in association with cassiterite.

Aquamarine was obtained in early times in various places in the Coimbatore district, Madras, and there are a few minor localities in Rajputana and Kashmir in India. Yellow beryl comes from Ceylon, but is not very common.

Beautiful green and yellow beryl is found in pegmatite veins in association with black tourmaline, quartz, feldspar, mica and other minerals, at various places in South-West Africa. The principal locality which is at Klein Spitzkopje, near Rössing on the Otavi railway, is noted as the home of the peculiar golden-yellow variety, heliodor, but it also produces excellent aquamarines and yellowish-green stones.

Beryl in several varieties, including the prized emerald, has been obtained from the Leydsdrop district, Transvaal. The associated minerals are tourmaline, quartz, apatite, feldspar and molybdenite. The emerald crystals, which are of the usual prismatic habit, have been found large enough, though typically flawed, to yield excellent stones of up to 5 carats in weight.

The fine blue crystals of beryl, which occur in the granite of the Mourne Mountains in Ireland, may be noted, even though they are not clear enough to be worth cutting; somewhat similar crystals are found at Limoges, Haute Vienne, France.

Beryl has a comparatively wide distribution, and has been reported from many other places, though seldom in either quality or quantity to encourage exploitation. Among these places are the Shinyanga district of Tanganyika and the San Luis Mountains of Argentina. Norway has supplied a few emeralds of very poor quality, and beryl has been said to have been found in China, in the Ta Ching Mountains of Sui Yuan and at Tzu Ching Kuan in I Hsien in Chihli.

As is usual, beryl crystals, when opaque, reach much greater dimensions than when they are transparent or translucent. Enormous opaque crystals have been found in Norway.

XXIV

TOPAZ

Topaz has been a popular yellow stone in jewellery, and often forms the principal stone in brooches or pendants, especially in old-fashioned articles. It is a general idea that all yellow stones are topazes, and all topazes are yellow; but neither statement is true. A very large number of yellow stones that have masqueraded as topaz are really the yellow quartz known as citrine. The latter was, indeed, at one time almost universally called by jewellers topaz, the qualification 'Brazilian' being used by them to distinguish the true topaz. Other species besides those mentioned yield yellow stones. Thus one of the varieties of corundum is the beautiful yellow sapphire, which is sometimes misleadingly called 'oriental-topaz', and yellow tourmalines are occasionally seen. The yellow chrysoberyl is always rather greenish in tint.

In bygone days when little was known about the essential characters of minerals all transparent yellow stones were indiscriminately called topaz. With increase of knowledge, mainly in the recognition of differences of hardness, jewellers separated the harder species by prefixes, thus 'Brazilian' for the topaz of mineralogists and 'oriental' for the yellow corundum, reserving topaz for the yellow variety of quartz known as citrine. The practice still persists, and 'king-topaz' and 'Indian-topaz' are used locally for the yellow corundum found in Ceylon and India respectively. It is equally wrong to call topaz by any other name such as chrysolite. By international agreement jewellers have decided to come into line with mineralogists and to restrict the name topaz to the native fluosilicate of aluminium.

Topaz is often perfectly colourless or only very faintly tinted. Yellow shades of varying degrees and depths, from a very pale yellow to a rich sherry-brown (plate I, 6) are common, and pure blue (plate I, 5) and pale-green stones, which not infrequently pass as aquamarines, are far from rare. Red and pink stones are very seldom seen in nature; the natural red stones, which have been found in Brazil, though very rarely, have been misleadingly called 'Brazilian-ruby', a term which should not be used. A beautifully coloured crystal is shown in its natural tints on plate XVII, 4. The lovely rose-pink topazes, which have long been conspicuous in modern jewellery, have resulted from the transformation of the brownish-yellow stones occurring in Brazil by means of the application of heat. The colour develops only on cooling, and does not seem to be subject to the fading on exposure to sunlight which characterizes many pink minerals. This transformation of colour is not difficult to effect. A keen collector was accustomed to amuse and interest his dinner guests by placing in the dining-room fire a crucible containing an incombustible powder in which a suitable topaz crystal was inserted and after the meal producing from the recovered crucible a pink crystal. The effect of heat is to cause some re-arrangement of the constituent atoms because all these pink topazes, while retaining their former crystal symmetry, possess high refractive indices and pronounced dichroism; at the same time the alien atoms diffused through the crystal which are responsible for its colour become differently grouped with a consequent change in the tint. It may be noted that it is not every yellow topaz that gains a permanent blush on warming; those from Ceylon, for instance, turn colourless, and the colour of the pale yellowish-brown crystals from the Urulga River in Russia fades on prolonged exposure to strong sunlight.

The precise meaning of the word topaz is uncertain. It passed into English from the Greek τόπαζος, or the Latin *topazus*, but it had a much older origin and may have been derived from a Sanskrit word meaning heat or fire. A clue was thought at one time to have been provided by Pliny's description of it:

> 'Topazus is a stone that is still held in very high estimation for its green tints: indeed, when it was first discovered, it was preferred to every kind of precious stone. It so happened that some Troglodytic pirates, suffering from tempest and hunger, having landed upon an island off the coast of Arabia known as Cytis, when digging there for roots and grass, discovered this precious stone: such, at least, is the opinion expressed by Archelaus. Juba says there is an island in the Red Sea called Topazos, at a distance of three hundred stadia from the main land; that the island is fogbound, so that sailors often have to search for it, and that, owing to this, it received its present name, the word topazin meaning to seek, in the language of the Troglodytae.' (Egregia etiamnunc topazio gloria est, suo virenti genere, et cum reperta est, praelatae omnibus. Id accidit in Arabiae insula, quae Cytis vocatur, in qua Troglodytae praedones, diutius fame et tempestate pressi, cum herbas radicesque effoderent, eruerunt topazion.

> Haec Archelai sententia est. Juba Topazion insulam in rubro mare a continente stadiis CCC abesse tradit, nebulosam, et ideo quaesitam saepe a navigantibus, ex ea causa nomen accepisse. Topazin enim Troglodytarum lingua significatione habere quaerendi). Loc. cit. book 37, ch. 8.

But there has probably been a confusion between the Greek word and a similarly sounding word in some oriental language. It is evident, however, from the description that topaz in Pliny's day did not mean the gemstone understood by that name to-day; if it were green in colour and came from an island in the Red Sea, it was probably our olivine (peridot). On the other hand, our topaz was probably included in Pliny's chrysolithus.

Topaz is a fluosilicate of aluminium, corresponding to the formula $Al_2(F,OH)_2SiO_4$, in which some of the fluorine is replaced by hydroxyl. It crystallizes in the orthorhombic system, the crystals being prismatic in habit and terminated by numerous pyramidal and dome faces, and sometimes a basal pinacoid. A doubly terminated crystal is illustrated in fig. 22, but crystals are often broken off at the lower end along the good basal cleavage (fig. 122).

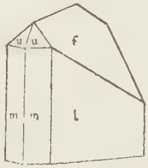

FIG. 122.—Topaz crystal, terminated by basal cleavage.

In accordance with the crystalline symmetry the refraction is biaxial in character, and since the mean is very near the least refractive index its sign is positive. The values of the least refractive index of gem material range from 1·607 to 1·632, and of the greatest refractive index from 1·616 to 1·640, the maximum birefringence remaining nearly the same, namely 0·008. The high values correspond to the Brazilian yellow stones and to the pink stones which have been heated; while the low values belong to the denser white and blue or greenish stones. The colour-dispersion is low, amounting only to 0·014 for the *B–G* interval. The dichroism of a yellow topaz is at least perceptible, one of the twin-colours being distinctly more reddish than the other, and that of the pink stones, which have been heated, is very marked.

Topaz is vitreous in lustre, and is often beautifully clear and limpid. It is often pyroelectric, especially when tested in small fragments, so that the appearance of full orthorhombic symmetry presented by complete crystals (p. 35) may be due to repeated twinning on a minute scale. It may, moreover, be strongly electrified by friction. When topaz is exposed to ultra-violet rays, little fluorescence is perceptible; the pink variety, however, displays the phenomenon very faintly at 6820 Å in the red, and also shows a band in the same position in the absorption-spectrum, the effect in both instances being due to the presence of chromium.

The variation of the specific gravity for topaz of differing colours is as follows: pink, 3·50 to 3·53; yellow, 3·51 to 3·54; colourless, 3·56 to 3·57; blue, 3·56 to 3·57. An anomalous bluish-white topaz, weighing 47·88 metric carats, gave the following values for the specific gravity and for the least and greatest refractive indices: 3·526, 1·611, 1·619. As was pointed out in a previous chapter (p. 135), topaz, compared with the gemstones generally, has much lower refractivity than would be expected from its specific gravity.

Topaz ranks 8 on Mohs's scale of hardness, and in this character is surpassed only among gemstones by chrysoberyl, corundum and diamond, but the interval between it and quartz (7) is much smaller than that between it and corundum (9). It possesses an easy cleavage parallel to the basal face, and for that reason topazes must be worn cautiously; a sharp blow may start feathers in the stone, even if it does not crack it. In testing the hardness of a topaz more than one direction should be tried, since the easy cleavage imparts a distinct grained character to the stone and it is much easier to effect a scratch along the trace of the cleavage plane. A cleavage flake of topaz is useful for studying the optical picture given by a biaxial crystal in convergent polarized light, for the acute bisectrix is at right angles to the flake. The 'eyes', however, will lie outside the limits of the field of view of a microscope, the optic axial angle being fairly large (the precise value depends upon the proportion of fluorine to hydroxyl in a particular specimen).

Topazes are generally, when of normal size, brilliant-cut in front and step-cut at the back, and the table facet sometimes is rounded; colourless stones are often cut in brilliant form. Topaz takes an excellent and dazzling polish. Owing to the easy cleavage great care is required in the cutting of a topaz lest incipient flaws be started.

At one time topaz was not considered to rank among the precious stones, but nowadays pieces of fine quality command high prices. The pink stones, to which frequent reference has been made, are in most demand. Since stones of any reasonable size are obtainable without difficulty, there is not the same sensational advance in the rate per carat with the size as has been remarked in the case of the more precious stones.

The Braganza stone in the Portuguese regalia, which was reputed to be a colossal diamond of 1680 carats, is believed to be a colourless topaz. The Mineral Collection in the British Museum (Natural History) contains two noteworthy faceted topazes. The first is a beautiful, step-cut, square-shaped, flawless, blue stone, weighing 614 metric carats, from Brazil. The second is a larger stone, colourless, brilliant-cut, oval-shaped, flawless, which weighs 1300 metric carats. Among the uncut crystals in that Collection are several unusual ones which should be noted. The first is a large, flattened, pale-blue with zones of deeper colour, water-worn crystal, which weighs 8 lb. (3·6 kg.) and measures about 7 by 5 inches on the prominent face and slightly over 2 inches in thickness (18 by 13 by 5 cm.); it was found at Marambaia, Serra do Chiffre, Minas Gerais, Brazil. There are two large, colourless, water-worn, prismatic crystals, of which the one, from Brazil, weighs 29 lb. (13 kg.), and the other, from Ceylon, weighs nearly 13 lb. (6 kg.); the latter was discovered about the middle of last century in use in a Fleet Street shop to prop the door open, the proprietor doubtless thinking it to be a lump of glass. Some evidence of the immense size to which opaque topaz can attain is afforded by the enormous crystal, weighing as much as 137 lb. (62 kg.), from Setersdalen, Norway, which is exhibited in aloof dignity.

Although the range of refractive indices of topaz overlaps that of tourmaline, there should be no risk of confusion, because the latter has more than double the amount of double refraction of the former. On the refractometer the two shadow-edges of tourmaline are easily separated in daylight, but those of topaz overlap even when most widely apart, and can be separated only in sodium light. The difference in refractivity easily differentiates topaz from quartz, with which it has so frequently been confounded. Indeed, the refractive indices of topaz readily identify it. The coloured fringes of the shadow-edges in daylight separate it from flint-glass, of about the same refraction, which is often used in cheap imitations. Owing to its high specific gravity topaz sinks in methylene iodide, whereas quartz, beryl and tourmaline, for which at times it might be mistaken, float.

Topaz occurs principally in pegmatite dykes and in cavities in granite, and is a conspicuous instance of the result of hot acid vapours upon rocks rich in aluminium silicates, for which reason it is commonly associated with minerals such as fluor, cassiterite (tinstone) and tourmaline, which are formed in a similar manner.

Magnificent crystals of topaz have come to light in two extensive mining districts in Russia, the one stretching along the eastern flank of the Ural Mountains and the other surrounding Nerchinsk in Transbaikalia. Fine green and blue stones have been found at Alabashka near

Sverdlovsk (formerly Ekaterinburg), and in the Ilmen Mountains farther to the south, where also topazes of the rare reddish hue have been picked up from the gold washings of the Sanarka River. Splendid pale-brown crystals, which lose their colour on exposure to sunlight, have come from the Urulga River on the northern side of the Borshchovochnoi Mountains, and good crystals accompany beryl in the Adun-Chalon Mountains, both localities being in the Nerchinsk district of eastern Siberia. Yellow, blue and green topazes have been produced by Kamchatka, in the extreme east of Siberia.

Many of the topazes used in jewellery of modern times have come from Brazil. The principal locality is near Ouro Preto in the south of Minas Gerais, where crystals of every shade of yellow from very pale to deep-wine tint have been found. Very rarely stones of a natural red tint have been seen here; the name 'Brazilian-ruby' has been proposed for them, but clearly is misleading and should not be used. In the north-east of Minas Gerais water-worn pebbles of blue and colourless topaz have been found in large numbers in river gravels near Arassuahy, the associated minerals being beryl and chrysoberyl.

Ceylon has provided a profusion of colourless, pale- and dark-yellow, and light-green, water-worn pebbles. The colourless stones found there are incorrectly termed 'water-sapphire', and the saffron-yellow topaz is misleadingly called 'Indian-topaz'. The light-green topazes are often confused with beryls and sold with them as aquamarines. It may be observed that the stones locally known as 'king-topaz' are really corundum (yellow sapphire).

Schneckenstein, in eastern Vogtland, Saxony, was the principal locality for yellow topazes in the eighteenth century. Some of the stones from here are characterized by a greenish shade of colour and for that reason have been given the name 'Saxon-chrysolite'; this use of the word chrysolite, which should be restricted to the mineral olivine, is wrong and should be avoided.

In the British Isles topaz has been found in beautiful, sky-blue, water-worn crystals in the Cairngorm area, Scotland, and in pale or colourless crystals in the Mourne Mountains, Ireland and at St Michael's Mount, Cornwall.

Japan has supplied an abundance of topaz crystals, but they are mostly colourless or only faintly tinged with blue, green, yellow or brown, very occasionally being parti-coloured. The brownish stones are said to lose their colour entirely on exposure to strong sunlight. The principal localities are near Takayama and Naegi in Mino Province, and Tanokamiyama in Omi Province.

Well-formed crystals, some colourless and others a pale blue, have been found in the pegmatite dykes at Klein Spitzkopje, Usakos, South-West Africa. Good crystals, of a somewhat deeper blue, have come from Jos, Central Province, Northern Nigeria and also from the gem gravels in Somabula Forest in Southern Rhodesia.

Colourless and bluish topazes occur in many parts of the United States, chiefly in California, Utah, Colorado and New Hampshire. Similar crystals have been seen in Flinders Island, near Emmaville in New South Wales, and in Tasmania. Topaz also occurs at Mogok in Upper Burma and in Madagascar.

XXV

SPINEL

Spinel as a gemstone labours under the serious disadvantage of being overshadowed at almost all points by its opulent and famous cousins, sapphire and ruby, and is not so well known as it deserves to be. The only varieties that are much valued as a gem are those which most resemble the true ruby; they are probably often confused, especially since in nature they are found in intimate association. Spinels of other colours are not very attractive to the eye, and are unlikely to be in much demand. The blue spinel is not only uncommon in nature, but the colour is also inclined to the steely shade of blue, and is much inferior to the superb tint of the true sapphire. Spinel is very hard and is therefore eminently suitable as a ring-stone, though it is seldom large and transparent enough for larger articles of jewellery.

The name used in mineralogy for the species is spinel, and no cogent reason can be advanced for not following the same practice in the case of the stones used in jewellery and using the name throughout, merely qualifying it, if desired, by the appropriate colour; thus, we can properly speak of red spinel, orange spinel, and so on. The long-established custom of calling the red spinel 'balas-ruby' or less often 'spinel-ruby' cannot be defended, and should be abandoned. The old name 'rubicelle' for orange-red spinel is scarcely more defensible. Those not versed in the characters of gemstones are certain to retain the impression that stones so called are akin to the red corundum, however much they may be told that they are quite distinct from it. It is, of course, wrong to use misleading terms in the hope of foisting the stones upon an unsuspicious public, and call the violet spinel 'oriental-amethyst', or the blue spinel 'sapphire-spinel'. Even more objectionable is the converse practice of using the word spinel in connexion with other species, and no such names as those following should ever be used by any one anxious for precision in nomenclature: 'Arizona-spinel' and 'Kandy-spinel', both of which are garnets. Nor should purplish-red varieties be called 'almandine-spinel', since almandine is the accepted name for a species of garnet (p. 335).

Spinel is magnesium-aluminium oxide, $MgAl_2O_4$. It was formerly described as an 'aluminate', but the crystal structure is that of an oxide. Each magnesium ion is surrounded by four oxygen ions and each aluminium by six oxygen ions; there are no complex ions in the structure to justify the older description. Spinel itself is an end-member of a group in which there is extensive isomorphous replacement. The magnesium ions may be replaced by ferrous iron (ceylonite, pleonaste, hercynite), by zinc (gahnospinel, gahnite) or by manganese; the aluminium may be replaced by chromium (picotite, chromite) or by ferric iron (chlorospinel).

The word spinel has reached us through the French *spinelle*, but the derivation of the latter is uncertain. On etymological grounds the most likely origin is spinella, the diminutive form of the Latin *spina* (thorn), from which our word spine is obtained. It is, however, not a very apt name for spinel crystals, and may at first have been given to a species, the crystals of which have a characteristically acicular habit, and later transferred to the one that it now denotes. The alternative suggestion that the word was derived from the Greek σπινθήρ (spark), through an unusual form, σπῖνος, in reference to the red colour of the most esteemed crystals, is plausible but not so probable. Balas comes from the late Latin word *balascus*, which is derived through the Arabic form, Badakshan, the name of the district which provided the finest stones in medieval times. Rubicelle is taken from the French, and appears to be a diminutive of *rubace*, another form of *rubis* (ruby). Pleonaste is the French word *pléonaste*, which is derived from the Greek word πλεοναστός (abundant), in allusion to the additional faces found replacing the solid angles of the octahedron. Picotite is named after Picot de la Peyrouse, who described the chrome-spinel.

When pure, spinel is colourless, but in nature such stones are very rare. Beautiful red stones, the so-called 'spinel-rubies' or 'balas-rubies', are well known, the colour being due to the presence of chromium as in the instance of the true ruby; the slightly yellowish tinge of the 'rubicelles' is due to the presence of iron, and manganese may be the cause of the tint in purplish-red varieties. So variegated is spinel that it is hardly feasible to enumerate all the shades between blue and red that it may assume. Stones which are rich in iron are quite opaque, but are sometimes used for ornamental wear. The greenish and brownish varieties are seldom used. Spinels of various tints are shown in natural colour on plate XX; a cut gahnospinel is to be seen on plate I, 9.

Like diamond, spinel crystallizes in the cubic system and occurs in beautiful octahedra or in flat triangular-shaped plates (fig. 123 and plate

XX, 11), the girdles of which are cleft at the corners, the plates being in reality twinned octahedra; a mode of twinning that is so characteristic of this species that it is commonly known as a spinel-twin when seen in other species. The octahedra are often irregularly developed, so that prominence is given to one of the faces or a pair of opposite faces, in which event the crystals will closely resemble those of the true ruby, because the differences in interfacial angles are not sufficiently pronounced to be readily discernible by eye.

Because of the crystalline symmetry of spinel its refraction is single, and it possesses neither double refraction nor dichroism; the pronounced dichroism of ruby and its absence in spinel form a simple way of discriminating between two gemstones of very similar appearance to the eye.

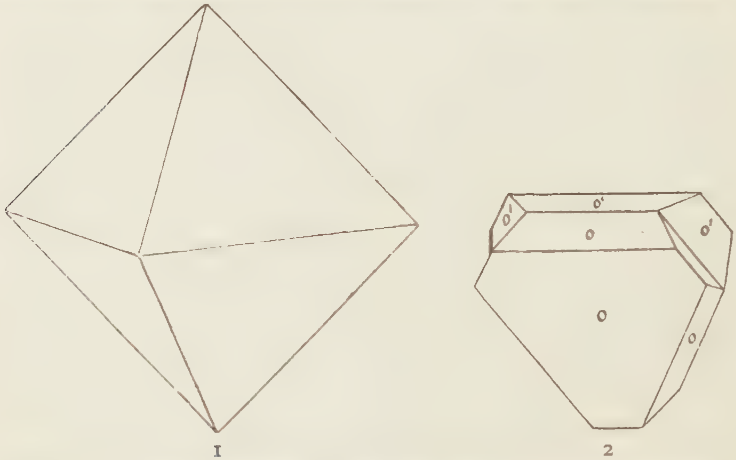

FIG. 123.—Spinel crystals: (1) simple, form *o* {111}; (2) twinned, form *o* {111}.

A consequence of the varying amount of isomorphous replacement of one element by another in spinel without any disturbance of the crystal form is a large variation in the refractive index, the value of which depends upon what elements are present. Since certain of them have strong tinctorial influence, the variation in the refractive index may be related to the colour of the stone; thus the value for red stones varies from 1·715 to 1·735 according to the percentage content of chromium, for blue stones from 1·715 to 1·747 according to the percentage content of zinc, and for other colours from 1·712 to 1·717, the normal value being 1·717. The colour-dispersion is small, amounting only to 0·020 for the *B–G* interval.

Spinels may exhibit fluorescence and absorption-spectra, though because of the varying degree of isomorphous replacement neither phenomenon is constant for all spinels. In some pink spinels, though not all, the fluorescence takes the form of a group of five bright lines in the spectrum, of which the two strongest lying at 6870 and 6750 Å respectively are a distinctly separated pair. Spinels of a pure red colour show a characteristic absorption-spectrum, in which the part of the green and the yellow lying between 4900 and 5950 Å has been almost completely blotted out, and there are a weak band at 6560 Å and a stronger doublet at 6840 and 6855 Å, all three in the red, besides other fainter bands. The intensity of the absorption-spectrum depends upon the depth of the inherent colour of the stone; it is markedly less if the colour be pink. Certain red spinels, which do not fluoresce, do not exhibit the bands in the red, the reason being that they owe their tint mainly to elements other than chromium, the presence of which gives rise to both the bands and the fluorescence.

Blue spinel possesses an absorption-spectrum, due to the presence of iron, which at its maximum has as many as ten bands. Most of them, however, are rather indefinite, but a strong one, lying at 4590 Å in the blue part of the spectrum, is very persistent and is visible in stones containing less than 2 per cent of iron oxide, and another, rather weaker, lying at 4800 Å vies with it.

The specific gravity of spinel for transparent material varies between 3·58 and 3·63, except in the case of the types that are rich in zinc, in which it may reach as high as 3·98. It may be noted that in gahnite the specific gravity ranges from 4·0 to 4·6; it is practically opaque. In the variety, ceylonite, the specific gravity rises with increasing percentage of iron to about 4·0; it is black and opaque.

Spinel is softer than the sapphire and ruby, though with hardness 8 on Mohs's scale it is scarcely inferior in lustre to these stones. It sometimes shows an imperfect cleavage parallel to the octahedron faces, which is possibly a parting due to twinning. Spinels are susceptible of a variety of treatment depending upon the purpose which they may be intended to serve. They may therefore be cut in brilliant form, step form, or a combination of the two, or in cabochon form. The only variety of spinel which meets with a general demand for jewellery purposes is the deep-red one, miscalled 'spinel-ruby', which approximates in appearance most closely to the ruby, but in price is far inferior to the latter.

The romantic history of the Black Prince's Ruby, long the pride of the British regalia, and of the Timur Ruby, the property of the British

Crown, both of them really spinels, has been given in a previous chapter. The immense red stone, now in the Diamond Treasury at Moscow, which is set at the apex of the crown made for the Empress Catherine II in 1762, is a spinel. Deep red in colour, clear and transparent, it is irregular in shape, since it still retains its original oriental cutting. It is still attached with a brilliant to a pin, and, after due allowance has been made for their combined weight, its estimated weight is 400 to 404 metric carats. The Louvre in Paris contains a beautiful, faceted spinel, 105 metric carats in weight, which was formerly one of those in the French crown. Tavernier is said to have purchased in India in 1665 three large red spinels weighing some 200 carats each. Two large spinels, weighing 81 and 72½ carats when cut, were shown at the London Exhibition of 1862. The Mineral Collection of the British Museum (Natural History) includes a large polished octahedron, weighing 355 metric carats, and a polished pebble, weighing 520 metric carats, both of which came from Burma, and the latter was among the treasures seized at the capture of the Summer Palace of the Emperor of China during the war 1860–61.

As has been pointed out in an earlier chapter, the synthesis of spinel has been successfully achieved by means of the inverted blowpipe method and has proved to be of exceptional scientific interest, because it was found as a result of these experiments that alumina in amount greatly exceeding that demanded by the composition of spinel could combine with magnesia in a solid solution without any tendency to disruption of the crystal structure. In nature no such alumina-rich spinels are known. The refractive index and specific gravity rise with the increasing proportion of alumina; thus for colourless material with a ratio of $MgO : Al_2O_3$ of 1 : 1 the specific gravity is 3·58 and refractive index 1·715, and with a ratio of 1 : 4 the corresponding values are 3·62 and 1·728. These synthetic stones may be distinguished from the natural spinel by their higher physical constants, their anomalous double refraction due to uneven strain in the structure, and their usually unnatural shade of colour.

Spinel may in general be most easily distinguished by its refractivity, which is appreciably lower than that of ruby, pyrope or almandine, with which it might be confused. Certain pyrope, however, resembles spinel very closely, and careful determination of both the specific gravity and the refractive index may be necessary for an assured discrimination; for instance, the values of the refractive index and specific gravity for pyrope from Australia are 1·733 and 3·67 respectively, but for spinel with nearly the same refractive index, 1·734, the specific gravity is 3·61. They may also be discriminated by the difference in their absorption-spectra (p. 105). Spinel is easily separated from the ruby with which it is so frequently associated and to which it is so similar in appearance by its single refraction and consequent absence of the dichroism which is the characteristic feature of ruby.

The finest gem material of spinel occurs in crystalline limestones and schists and in the alluvial deposits which result from the disintegration of these rocks. Spinel of other types is a constituent of certain igneous rocks as well as of rocks which arise from their alteration.

The red spinel and ruby have been discovered mixed together in the gem gravels of Mogok, Upper Burma. Curiously enough, while the rubies are generally waterworn, the spinel is found in perfect octahedra, the colour of which is equally perfect. Ceylon has supplied in addition to the red variety beautiful violet and blue stones, and, as one of its names would suggest, the black variety, pleonaste or ceylonite, is common. Spinel is also mixed with sapphire and ruby in the alluvial deposits of Chantabun in Siam. At one time it was abundant in the ruby mines of Badakshan in Afghanistan; indeed, it is from its old form, Balascia, that the word balas is believed to have been derived.

XXVI

GARNET FAMILY

The important family of minerals which are known under the general name of garnet provides an apt illustration of the fact that rarity is an essential condition if a stone is to be accounted precious. Owing to the large quantity of garnets of a not very attractive shade of yellowish-red that were poured upon the market from the mines in the old kingdom of Bohemia during the latter half of last century the species became associated with cheap and often inartistic jewellery, and acquired a stigma that completely prevented its attaining any popularity with those professing a nice taste in gemstones. Despite, however, the cloud which overshadowed this family of gemstones, it did not disappear from high-class jewellery, because the prejudice of customers was met by assigning to the red garnet, which was found in association with diamond at the Kimberley mines, and to the green garnet from the Urals the apparently more attractive, but certainly wholly incorrect, names of 'Cape-ruby' and 'Uralian-emerald' or 'olivine' respectively. The use of olivine in this sense is a particularly heinous offence, because it is a long-established name in science for an important and very different mineral species, magnesium-iron silicate, a variety of which under the appellation, peridot, holds a high position among gemstones.

It is likely and even probable that in days before jewellers had devoted much attention to gemmology many garnets were given other names owing to genuine mistakes in identification. Many a fine almandine may still masquerade as a true ruby; by eye alone it is often at least very difficult to distinguish them with absolute certainty. An instructive instance of this confusion came to the author's notice some years ago. A lady one day had the misfortune to fracture one of the stones in a ruby ring, which had been in the possession of her family for upwards of a century, and was originally purchased from a leading firm of jewellers in London. She took the ring to her jeweller, and asked him to have the stone replaced by another ruby. A day or two later he sent word that it was scarcely worth while to put a ruby in, because the stones in the ring were paste. Naturally distressed at such an opinion of a ring which had always been held in great esteem by her family, the lady consulted a friend, who suggested showing it to the author. A glance was sufficient to prove that, if the ring had been in use so long, the stones could not possibly be paste because of the excellent state of their polish, and a test with a refractometer showed that the stones were really almandine and not ruby. Beautiful as the stones were, the ring was probably not worth one-tenth of what the value would have been had the stones been rubies.

To the student of mineralogy garnet is for many reasons of peculiar interest. It affords an excellent illustration of the facility which certain elements possess for replacing one another without any great disturbance of the crystalline form. Despite their apparent complexity in composition, all garnets conform to the same type of formula; calcium, magnesium, ferrous iron and manganese, and again aluminium, ferric iron and chromium, may replace each other to a large extent, and it would be rare, indeed, to find a stone that agrees in composition exactly with any of the chemical formulae given below for the several varieties of garnet:

General formula, $X_3Y_2(SiO_4)_3$

Pyrope, $Mg_3Al_2(SiO_4)_3$	Grossular, $Ca_3Al_2(SiO_4)_3$
Almandine, $Fe_3Al_2(SiO_4)_3$	Andradite, $Ca_3Fe_2(SiO_4)_3$
Spessartite, $Mn_3Al_2(SiO_4)_3$	Uvarovite, $Ca_3Cr_2(SiO_4)_3$

These formulae really correspond to the limiting members constituting the family, and the composition of any garnet may be expressed in percentages of these limiting members. In practice the names of the varieties are used loosely for all stones approximating in composition to that corresponding to the particular formula, and it might be difficult to decide where to fix the boundary between any pair of the varieties. There appears to be a continuous series from pyrope to almandine, by the substitution of iron for magnesium; the name, rhodolite, has been used for members of this series near to pyrope and the name, pyrandine, for the middle of the range. Continuous series also exist between almandine and spessartite, and between grossular and andradite, but the extent of substitution of calcium by manganese, magnesium and ferrous iron is limited.

The history of the name, garnet, given to the family, is rather confused. It came into English from the old French word, of which there were two forms, *gernat* and *grenat*, and which had descended from the Latin *grenatus*. The root of the latter is gar and comes from a Sanskrit word, meaning to wear away. This meaning took different paths: it appeared in Greek as γέρων (old man) and in Latin as *granum* (seed). The adjective *granatus* means having many seeds, and consequently the substantive *granatum* was applied to the pomegranate. The mineral possibly received its name, because its colour is similar to that of the pulp of the seed. An alternative derivation is from the Latin *granum*, which means grain and also cochineal and red dye, the name being suggested by the red, the best known colour of garnet. Either derivation is more plausible than a third, which leans towards the seed meaning, and supposes the choice of the word, garnet, to have been determined by the seed-like appearance of the crystals, so nearly spherical in shape, when embedded in their pudding-like matrix. It may be noted that the word, granite, has the same origin, having been assimilated from the Italian *granito* (grained), which was derived from the Latin *granum*.

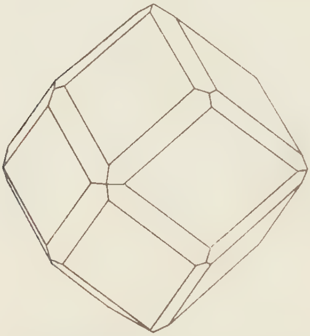

FIG. 124.—A crystal of garnet of dodecahedral habit.

FIG. 125.—A crystal of garnet of icositetrahedral habit.

Garnet crystallizes in the cubic system of crystal symmetry, its crystals being usually of dodecahedral or icositetrahedral habit (figs. 124 and 125). Highly modified crystals, especially when worn by weather or water, are nearly spherical in shape.

Refined observations have shown that garnet is seldom homogeneous. Although singly refractive, so far as can be determined by means of a refractometer or by the deviation of light through a suitable pair of faces or facets, garnets, when viewed through a polarizing microscope, almost invariably display a small amount of local double refraction. It is, indeed, so small that the transition from light to darkness is not sharp as with normal double refraction, but is prolonged into a kind of twilight. The explanation is that on cooling from the point of crystallization to normal temperatures the crystal has suffered a slight contraction of structure which has set up local stresses in it.

In view of the crystal symmetry, garnet is singly refractive, except for the, in practice, negligible amount of double refraction just mentioned. There is therefore no dichroism, a test which helps to discriminate the purplish-red almandine from ruby. In consequence of the considerable amount of isomorphous interchange of elements in garnet the refractive index and the specific gravity have the wide ranges of 1·74 to 1·89 and 3·60 to 4·20 respectively; lower values of the specific gravity are known, down to 3·45, in massive material though not in single crystals of gem quality. Some garnet is sufficiently fibrous in structure to display, when suitably cut and illuminated, a stellar appearance with four or six rays, according as it is viewed in the direction of a cubic or a tetrahedral axis of symmetry. The lustre varies from vitreous to resinous. The hardness is about the same as that of quartz, but varies slightly, grossular and andradite being a little softer, pyrope, spessartite and almandine a little harder, and uvarovite about the same. These physical properties will be considered in greater detail when the several varieties are described. All the varieties, except uvarovite, are fusible when heated before the ordinary blowpipe, and small fragments melt sufficiently on the surface in the bunsen gas-flame to adhere to the wire holding them, a test of some practical value for separating fragments of the red garnets, pyrope and almandine, from corundum, spinel and zircon of very similar appearance.

The varieties that are of greatest service to jewellery are the fiery-red pyrope, the crimson and columbine-red almandine and the emerald-green andradite (demantoid). The nearer the two first approach the ruddy hue of ruby the better they are appreciated. Grossular has in the past been in some demand, but it possesses too little perfection of transparency and its colour tends too much to not very attractive shades of yellow to accord with modern taste. The sub-variety of andradite known as demantoid provides lovely stones, both pale and dark emerald-green in colour, of brilliant lustre and large colour-dispersion, which are admirably adapted for use in pendants or necklaces; on account of their comparative lack of hardness, which is less than that of quartz, it would be unwise to risk them in rings. In some demantoid the colour has a yellowish tinge, and such stones are consequently not in much demand. Uvarovite also occurs in stones of an attractive emerald-green colour, but unhappily they are seldom, if ever, large enough for cutting purposes. Spessartite, when transparent and of good colour, is pleasing to the eye, but the amount of gem material is far too limited to permit this variety of garnet to come into general use; a splendid faceted stone, 6·21 metric carats in weight, is in the Sir Arthur Church collection in the British Museum (Natural History), and a still larger stone, 12·01 metric carats in weight, is in the Museum of Practical Geology. Cut garnets of various tints are shown in natural colour on plate I.

The old style of cutting used for garnets was almost invariably the rounded or cabochon form; to-day they are normally faceted, either step-cut or mixed-cut with usually a brilliant top and stepped facets below.

Besides providing gem material, garnet has a use in industry as an abrasive, especially in connexion with wood polishing.

Composed as it is of the principal elements which make up the earth's crust, it is not surprising that garnet should be a prominent constituent of many rocks, igneous, sedimentary and metamorphic. The material most suitable for gem purposes occurs chiefly in crystalline schists, metamorphic limestones, and alluvial deposits. Pyrope and demantoid are provided by peridotites and the serpentines resulting from them; almandine and spessartite, on the other hand, come mostly from granites.

The principal varieties of garnet are as follows:

1 GROSSULAR

This variety is usually known in science as grossular, a word which is derived from *grossularia*, the botanical term for gooseberry, in allusion to the colour and appearance of many of its crystals, or as hessonite or, less correctly, essonite, words derived from the Greek ἥσσων (less), because of its inferior hardness as compared with zircon, which is often of similar colour. The golden-yellow grossular is alternatively known as cinnamon-stone, the name being suggested by its colour. The terms hyacinth or jacinth are used for the orange and reddish-brown grossulars, but it would obviate the risk of confusion if they were reserved for zircon, of similar colour, to which they more properly belong. The risk of a mistake is lessened, or even removed altogether, if the term be used in conjunction with the name of the group in the following manner: hyacinth-garnet.

Grossular is the commonest of the lime-garnets. It corresponds ideally to the formula $Ca_3Al_2(SiO_4)_3$, but there may be extensive replacement of aluminium by ferric iron and chromium. Magnesium, ferrous iron and manganese may replace the calcium to some extent.

In colour, grossular may be pale olivine-green, yellowish, orange, pink or reddish-brown, but only the yellowish and orange stones are much used in jewellery. Neither the gooseberry-tinted stones, to which the name, grossular, is most properly applied, nor the rose-red stones are found sufficiently transparent to give satisfaction as gemstones. The cinnamon-stones and the hyacinth-garnets have mostly a curiously granular structure, just as if they were composed of tiny grains, imperfectly fused together; this peculiar appearance is readily discernible if their interior be viewed through a lens of moderate power.

The refractive index and the specific gravity of grossular normally range from 1·741 to 1·748 and from 3·60 to 3·80 respectively. The massive green material from the Transvaal has rather lower values: 1·72 to 1·73 and 3·45 to 3·50; its higher refractive index readily separates it from either jadeite or nephrite. Occasionally the light transmitted by hessonite, when studied with a spectroscope, displays faintly the absorption-spectrum characteristic of almandine. Its dispersion for the *B–G* interval is moderate, amounting to 0·028.

In hardness, grossular on the whole comes slightly above quartz. Heated before a blowpipe, it easily fuses to a greenish glass.

The most suitable material has been found in some profusion in the gem gravels of Ceylon, in which it is closely associated with zircon of almost identical appearance; both are called hyacinth or jacinth, but this name is properly restricted to zircon. The yellow cinnamon-stones are even commoner. Grossulars from other localities, although attractive as museum specimens have been neither large nor clear enough for cutting purposes. Switzerland at one time supplied good stones, but the supply has long been exhausted. Fine brownish-green crystals have come from Vilui River, a tributary of Lena River, Siberia. Grossular has been found with other garnets, almandine and pyrope, in eastern Brazil. The beautiful pink grossular in white marble from Xalostoc, Morelos, Mexico, has been called landerite (after Carlos F. de Landero), xalostocite (after the locality where it was found), or rosolite (after its colour).

A light-green, massive material described as grossular has been found about 40 miles (64 km.) west of Pretoria in the Transvaal. In appearance it is not unlike some jade, and it has been sold as a substitute for jade under the misnomer, 'Transvaal-jade'. Analysis shows that the mineral is a member of the hydrogrossular series. Associated with the green material are smaller amounts of other colours, notably pink and grey.

2 PYROPE

Almost ruby-red in colour (plate I, 8), pyrope has been one of the most popular of the varieties of garnet. When pure, it is a magnesium-aluminium silicate, corresponding to the formula $Mg_3Al_2(SiO_4)_3$, but it almost invariably contains a small to considerable amount of ferrous iron and thus approaches almandine in composition. It is, in fact, hardly feasible to draw a sharp distinction between the two varieties, and both are included in precious garnet. Pyrope is crimson in colour, deepening to a purplish shade as the constitution approaches that of almandine; if the colour be tinged with yellow the stone loses much of its value. Its name is derived from πυρωπός (fire-like), in obvious allusion to its characteristic colour. The attempt that has so often been made to stimulate trade in the stones by pretending that they are other than what they really are is most reprehensible, and such names as 'Cape-ruby', 'Arizona-ruby', 'Colorado-ruby', 'American-ruby', 'Adelaide-ruby' and 'Kandy-spinel', relating to the products of various localities, should be abandoned. The sub-variety, rhodolite (plate I, 4), derives its name from the Greek words ῥόδον (rose) and λίθος (stone), in allusion to its rose-red or rhododendron-red colour.

The refractive index and specific gravity of pyrope may be considered to range from 1·730 to 1·751 and from 3·65 to 3·82 respectively, but since it merges into almandine the upper limit of each range is arbitrary. The values for the stones from South Africa are 1·740 to 1·750 and 3·68 to 3·73, and from Ceylon, 1·730 to 1·750 and 3·65 to 3·80. The values for the sub-variety, rhodolite, are 1·760 and 3·84; it shows in the spectroscope the absorption bands characteristic of almandine. These bands become more evident as the percentage of iron in pyrope increases. The dispersion for the *B*–*G* interval is moderate, amounting to 0·024. Pyrope is very slightly harder than quartz, and is therefore ranked as 7¼ on Mohs's scale. Like all varieties of garnet, pyrope is easily recognized by the absence of dichroism and by its refractive index. The similarity which it occasionally bears to spinel has already been discussed (p. 326).

Although usually quite small in size, pyrope has occasionally attained to considerable dimensions. The Kaiser Rudolph II is said to have had a large one in his possession, which was valued at 45,000 thalers (about £7000). The former Imperial Treasury at Vienna contained a red stone as large as a hen's egg, which was probably a pyrope. Another somewhat smaller, about the size of a pigeon's egg, is in the Green Vaults at Dresden, and one, weighing 468½ carats, set in an order of the Golden Fleece, belonged to the kings of Saxony.

An enormous quantity of small red pyropes, mostly with a slight tinge of yellow, has been mined over an extensive area near Trebnitz in the north-east of Bohemia, and a considerable industry in cutting and marting them grew up at Bilin during last century, but eventually declined owing to the competition of even better material from elsewhere, notably South Africa, and particularly to its exclusion from fashionable jewellery. Beautiful pyropes are associated with diamond in the blue ground of the South African mines, the finest examples being found at the De Beers and the Kimberley mines. Similar stones have been discovered in Arizona and Colorado in the United States, and in Australia, Southern Rhodesia, Argentina, Brazil and Mexico. Excellent material, rich in iron, and therefore inclined towards almandine, has been mined in the hornblende-schist and detritus from it near Namaputa in Lindi Province, Tanganyika; it was sold as 'Fashoda-ruby' or 'Cape-ruby', both most incorrect terms. Similar stones, though not of such good gem quality, have come from Madagascar. The charming rose-red or pale-violet sub-variety, rhodolite, was found in Cowee Valley, Macon County, North Carolina, but in too limited quantity to acquire a position in jewellery that its qualities deserve.

3 ALMANDINE

Almandine is in its limiting member the iron-aluminium variety of garnet corresponding to the formula $Fe_3Al_2(SiO_4)_3$, but the composition is very variable, and, as has been pointed out above, no precise demarcation can be drawn between it and pyrope. In colour it is deep crimson and violet or columbine-red (plate I, 2 and 3), but with increasing amount of iron it becomes brown and black, opaque and unsuitable for ordinary jewellery. Its name is a corruption of alabandine, from Alabanda in Asia Minor, where in Pliny's time the finest stones were cut and sold; for the sake of uniformity in nomenclature some prefer the form, almandite. Almandine has sometimes been known as Syriam, or incorrectly Syrian, garnet, because at Syriam, once the capital of the ancient kingdom of Pegu, which now forms part of Lower Burma, such stones were cut and sold. Crimson stones, cut in cabochon form, were formerly used extensively for enriching metal-work, and about the middle of last century were popular for ornamental wear; they have now returned to favour. Such stones have been aptly termed carbuncles—a word derived from the Latin *carbunculus* (little spark). In Pliny's time, however, the word had a much wider meaning and was used indiscriminately for all crimson-red stones.

> 'In the first rank among these is carbunculus, so called from its resemblance to fire, though in reality it is proof against the action of that element: hence it is that some persons call these stones acaustoi.' (Principatum habent carbunculi, a similitudine ignium appellati, cum ipsi non sentiant ignes, ob id a quibusdam apyroti vocati.) Loc. cit., book 37, ch. 7.

The refractive index and specific gravity of almandine range from 1·751 to 1·811 and from 3·90 to 4·20 respectively, the lower limit in each instance corresponding to the upper limit of pyrope. In the case of black opaque stones the specific gravity may be as high as 4·25. Almandine is one of the hardest of the garnet varieties, and its hardness is represented by the symbol 7½ on Mohs's scale. It displays only moderate colour-dispersion, the amount being 0·024.

The most interesting and curious optical feature of almandine is the remarkable and characteristic absorption-spectrum revealed when the transmitted light is examined with a spectroscope (plate I, 1). Sir Arthur Church, in 1866, was the first to describe the phenomenon. It is displayed most vividly by violet almandine, and is, indeed, the cause of the peculiar colour, which is the result of the mixture of red and blue. The principal bands are centred at 5760, 5270, 5050 Å in the green, and 4620 Å in the blue (p. 108).

Almandine of good quality commands rather better prices than does pyrope. Almandine is distinguished from other red stones by its characteristic absorption-spectrum and from ruby, for which it may occasionally be mistaken, also by the absence of dichroism. Confirmatory evidence is afforded by the high refractive index, which may be beyond the reach of many refractometers.

Although almandine is a common mineral, material of a quality suitable for jewellery has been found at comparatively few places. It has turned up in the gem gravels of Ceylon, but not so plentifully as grossular, and has been wrongfully called 'Ceylon-ruby' or 'Kandy-spinel', because in appearance it resembles ruby and spinel in colour. Almandine has also been found in a hornblende-schist near Trincomali on the north-east coast of Ceylon. Good stones have been mined in various parts of India, especially from mica-schist in the States of Jaipur and Kishangarh and in Rajputana; they are nearly all cut at Delhi or Jaipur. Brazil has provided good material, especially in the Minas Novas district of Minas Gerais, in Rio de Janeiro and in the monazite sands along the coast. Almandine occurs in Madagascar, Australia, Uruguay and in many parts of the United States. Some of the material supplied by Tanganyika might be regarded as almandine instead of pyrope. Some almandine has been found in the Zillertal, Tyrol.

4 SPESSARTITE

If only spessartite of gem quality were found in sufficient quantity, its aurora-red colour would render it most acceptable for use in jewel-

1. Fluor crystal (octahedron, in matrix). 2. Euclase crystal. 3. Olivine. 4. Olivine. 5. Spinel. 6. Spinel. 7. Spinel. 8. Olivine. 9. Olivine. 10. Spinel crystal (octahedron). 11. Spinel crystal (twin). 12. Spinel crystal (flattened octahedron). 13. Fluor. 14. Hiddenite. 15. Kunzite. 16. Spodumene. 17. Fluor (twinned crystal)

XX. GEMSTONES

lery. The name is properly applied to a manganese-aluminium silicate, corresponding to the formula $Mn_3Al_2(SiO_4)_3$, but in nearly all spessartites some of the manganese is replaced by ferrous iron and some of the aluminium by ferric iron. Spessartite is derived from Spessart, a hilly district in north-western Bavaria, where it has been found; the French form, spessartine, is sometimes used instead.

The colour of spessartite is usually aurora-red or brownish-red, but may be also yellow or orange-brown; so far as it may be due to the influence of the manganese content, it is liable to alteration on exposure to sunlight. Its refractive index and specific gravity are high, ranging from 1·79 to 1·81 and from 4·12 to 4·20 respectively, and its hardness slightly exceeds that of quartz, being about 7¼ on Mohs's scale.

Suitable spessartites are so rare as to be curiosities, and there is no regular market. The fine stone in the British Museum (Natural History), which has been mentioned at the beginning of this chapter, is very exceptional; another cut from the same crystal is said to have been in a Russian collection. A fine spessartite, 12·01 metric carats in weight, which contains some iron in place of the manganese, is in the Museum of Practical Geology.

Spessartite, somewhat resembling some grossular in appearance, has been found in the gem gravels in Ceylon; in limestone-rock and river-gravels in Minas Gerais, Brazil; at Amelia Court House, Virginia, and Ramona, San Diego County, California, United States; and in the Broken Hill lode, New South Wales, Australia. Yellowish-orange crystals occur in pegmatite in Madagascar.

5 ANDRADITE

Once contemptuously dismissed as common garnet, andradite sprang prominently into the ranks of gemstones by the discovery of the magnificent sub-variety, for which the name demantoid was coined. At the best its colour is emerald-green, but varies from that through a pistachio tint to an olive-green; it is doubtless due to the presence of chromium. The following terms, which have from time to time been proposed for it by sections of the jewellery trade, should never be used; they are incorrect, and their use can only mean an attempt to deceive the public: 'Ural' or 'Uralian-emerald', 'olivine' or 'Ural-olivine', 'Ural' or 'Siberian-chrysolite'. The term olivine-garnet, the use of which appears to have been approved by the jewellery trade, is equally unsatisfactory, because of the implication that the stone is a species intermediate between garnet and olivine. It cannot be too strongly emphasized that for well over a century the name olivine has been in use in mineralogy for the magnesium-iron silicate, which is an important mineral constituent of basic igneous rocks and is quite different from garnet. As is explained in a later chapter, the precious olivine is known as peridot. The accepted name of the variety, demantoid, is derived from the Dutch word *demant* (diamond), with the addition of a modifying termination. Although it might be argued that the name is bad, because the stone has nothing to do with diamond, its adamantine lustre and its large colour-dispersion do fully justify the name; in fact, even the most unsophisticated is unlikely to be misled by it. Topazolite is the yellow sub-variety, and is so called because it resembles the yellow topaz in colour; the name has been recognized by mineralogists, but it would clearly be preferable that it should be dropped from the nomenclature of gemstones. Melanite, which is derived from the Greek μέλας (black), is the black andradite, which has been used for mourning jewellery.

Andradite is strictly a calcium-iron silicate, corresponding to the formula $Ca_3Fe_2(SiO_4)_3$, but as usual the composition may vary considerably between different stones; for instance, some of the calcium may be replaced by magnesium or manganese and the ferric iron by aluminium.

Demantoid has a high refractive index, varying from 1·888 to 1·889, and may therefore be cut in the brilliant form with good results, especially since its colour-dispersion, 0·057 for the *B–G* interval, is almost the highest of any gemstone. Its specific gravity is also high, varying from 3·82 to 3·85; the range runs a little higher, up to 3·90, for andradite generally. Unfortunately andradite is the softest of the garnets, its hardness ranking only 6½ on Mohs's scale, and this comparative softness limits the safe use of demantoid to such articles of jewellery as pendants or necklaces, in which it is not so likely to be rubbed when worn. The yellow variety would make an effective gemstone, but it is never found large and clear enough for the purpose. A faceted demantoid is shown in natural colour on plate I, 13.

Demantoid is the most valuable of the garnets. It is easily distinguished from any other green gemstone by its high refractive index, single refraction and high colour-dispersion.

The only places where demantoid has been found lie in the regions abutting on either side of the Urals, the finest examples emanating from the Sissersk district on the western side, where it occurs in a serpentine beside the Bobrovka stream, a tributary of the Chusovaya River. Yellow andradite has been found in beautiful little crystals in Ala valley, Piedmont, Italy, and at Zermatt, Switzerland, but they are too tiny for gem purposes.

6 UVAROVITE

The pleasing green variety of garnet known as uvarovite is a calcium–chromium silicate, corresponding to the formula $Ca_3Cr_2(SiO_4)_3$, but some of the chromium is always replaced by aluminium. It was named after Count S. S. Uvarov, President of the St Petersburg (Leningrad) Academy. It has an attractive colour, no doubt due to the presence of chromium, and is, moreover, fairly hard, ranking 7½ on Mohs's scale; but it is unknown in jewellery because it has never been found in pieces large enough for cutting. Its refractive index is high, 1·87, while its specific gravity is relatively low, about 3·77. Unlike its kindred varieties, it cannot be fused by heating with an ordinary blowpipe.

Uvarovite was first found in the Urals, and has since turned up in various parts of the world, in the Pyrenees and the Himalayas, and in Silesia. AT HAGDALE, UNST (SHETLAND) IN SERPENTINE.

XXVII

TOURMALINE

Tourmaline is unsurpassed by any other gemstone, even corundum, in the glorious galaxy of colours that it displays, and at the present time it has risen high in the ranks of jewellery, thanks to the prodigal profusion in which nature has formed it, particularly in California and in Brazil. Its comparative softness militates against its use in rings, but it is admirably fitted for service in such articles of jewellery as pendants, ear-rings and brooches, the stones of which are little liable to rubbing during wear, because fairly large, clear pieces of a wide choice of colour are obtainable without much difficulty.

The lovely rose-red or pink rubellite is the best known of the varieties to which distinctive names have been given. Achroite is the colourless tourmaline, which is very seldom seen; indicolite or indigolite and siberite are the indigo-blue and the violet-red varieties respectively; and schorl is the black, opaque material. It would perhaps make for clarity if all these varietal names were abandoned in favour of a straightforward description as pink tourmaline, blue tourmaline and so forth. The following terms, which have been in use for varieties of other colours, are obviously misleading and incorrect, and should be discarded: 'Brazilian-emerald' (green), 'Brazilian-sapphire' (blue), 'Brazilian-peridot' (yellowish-green) and 'Ceylon-chrysolite' or 'peridot' (honey-yellow). Emerald, sapphire and peridot are varieties of beryl, corundum and olivine respectively, and chrysolite is an alternative name for olivine; all these species are quite distinct from tourmaline.

The range of colours seen in tourmaline is remarkable, though perhaps not really surprising if the complexity of its composition be considered. Colourless stones, which are called achroite, are rare, though commoner in California than in most of the tourmaline localities. The stones that are most suitable for jewellery purposes are comparatively free from iron, and apparently owe their wonderful tints to the presence of alkali metals; lithium, for instance, appears to be responsible for the beautiful tint of the highly prized rubellite, and magnesium for the brown stones of various tints. Tourmaline may also show various shades of green, blue and yellow. When rich in iron, it is black and opaque, or nearly so. It is the striking peculiarity of tourmaline that its crystals are rarely uniform in colour throughout; usually they are differently coloured in parts, the several tints being in remarkable contrast, and the boundaries between the parts being sharp and abrupt. Sometimes the parts are segments separated by planes at right angles to the length (that is the principal crystallographic axis) of the crystal, and sometimes they are cylindrical, or nearly cylindrical, zones, the axes of the several surfaces being parallel to the length of the crystal. In the latter instance a section of the crystal cut perpendicular to its length shows zones of at least three contrasting tints. The core is generally red, the next zone being white with a green zone on the outside; the name 'water-melon tourmaline' is sometimes applied to zoned crystals of this kind. Tourmaline may, indeed, be found of almost every imaginable tint, except the green of the emerald and the blue of the sapphire. A crystal and a section are shown in natural colour on plate XVII.

The name of the species, tourmaline, was taken from the Sinhalese word *turmali*, and was first used when a parcel of these gemstones was brought to Amsterdam from Ceylon in 1703; in the island, however, the local jewellers are apt to use it for the yellow zircon somewhat similar in appearance to the tourmaline and found with it. Achroite comes from the Greek word *ἄχροος* (without colour), because of its absence of colour. It is usual to speak of a white stone as colourless, although logically, since such a stone transmits with no, or at least even, abatement the whole of the visible spectrum, it would be more correct to call it full of colour; on that principle a colourless stone would be black.

Schorl was derived from an old German mining term, *schörl*, which was used with suitable prefix for the conspicuous minerals associated with the one being exploited; thus, white schorl was albite, blue schorl haüynite, red schorl rutile and violet schorl axinite. Schorl was originally applied to hornblende as well as to black tourmaline, but ultimately was restricted to the latter. Schorl is a literal rendering of the German word; among the many alternative spellings in use in early days some, such as schirl or shirl, attempted to reproduce its pronunciation. The green tourmalines from Brazil, which were introduced into Europe in the seventeenth century, were then known as 'Brazilian-emerald'. In those dark ages when general ignorance of the character of minerals was prevalent there was a tendency to group stones together according to their colour merely distinguishing different kinds, if required, by a locality prefix; there is now no excuse for retaining a misleading name of this kind, particularly since true emeralds of a pale colour are actually found in Brazil. Violet-red tourmalines from Siberia have been termed 'Siberite' but there is no need for such a name.

In chemical composition tourmaline is an extremely complex borosilicate, corresponding to the general formula $XY_9B_3Si_6(O,OH,F)_{31}$, where X stands for sodium (and potassium) and calcium (and manganese), and Y for aluminium, titanium, iron, manganese, magnesium and lithium. The noteworthy features of the constitution are that the atoms replace one another regardless of their normal valencies in the two groups X and Y, manganese is common to the two, and the only ratio which is constant is that of boron to silicon, namely 1 to 2. It would scarcely have been anticipated, for instance, before the revelations resulting from X-ray investigations (p. 49) that aluminium, the oxide of which is Al_2O_3, would be replaceable by lithium, the oxide of which is Li_2O. Nevertheless, the general formula given above does satisfy all the published analyses, if it be remembered that the accuracy of the older ones is open to question, not only because analytical methods were not so precise then but also because the presence of certain elements, for instance fluorine, may not have been suspected and the relevant determinations were consequently not made.

Tourmalines may be divided into the following three different types, each of which grades into the other two with no well-defined boundary intervening between them:

(*a*) Alkali tourmaline, containing a considerable amount of sodium, potassium, or lithium;

(*b*) Magnesium tourmaline, containing much magnesium;

(*c*) Iron tourmaline, containing much iron.

The finest gem material is to be found in the first type, rubellite, for instance, being a lithium tourmaline. Colourless and brown stones are in the second type, and the third type consists of the commonest tourmalines, which are black and opaque.

To the crystallographer tourmaline is one of the most interesting of minerals. It crystallizes in the ditrigonal pyramidal class of the trigonal system (p. 36) and the two ends of its crystals are different in character. If they are terminated at both ends, the development is often obviously different at each of them (fig. 126), suggesting a directional character in the atomic structure, termed polarity, which is borne out by other physical properties. The crystals are usually prismatic in form, the prism faces being striated, and, if cut at right angles to the common direction of the edges of the prism faces, would be triangular in shape.

In accordance with its crystalline symmetry, tourmaline is doubly refractive, and the birefraction is uniaxial in character, the direction of single refraction being parallel to the edges of the prism faces. Since the chemical composition varies considerably from stone to stone, some variation in the physical properties is only to be expected, but as regards the refractive indices it is not large, because stones rich in iron, which are likely to be highly refractive, are too dark to be used as gems. The values of the extraordinary and the ordinary indices range from 1·620 to 1·628 and from 1·636 to 1·644 respectively; the amount of birefringence varies from 0·014 to 0·021, the low values being exceptional, and is usually 0·019 for green stones and 0·017 or 0·018 for paler stones. Occasionally dark stones may be met with which have values as high as 1·627 and 1·657 for the extraordinary and the ordinary indices respectively, the birefringence also being high, 0·030. Since the ordinary is greater than the extraordinary refractive index the double refraction is negative in sign. The colour-dispersion for the *B–G* interval is not large, amounting only to 0·017; but, since the attraction of tourmaline depends upon the intrinsic colour, the question of the amount of colour-dispersion that it possesses is not very material.

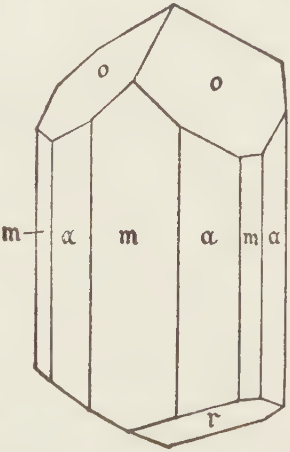

Fig. 126.—Tourmaline crystal: forms *a* {11$\bar{2}$0}, *m* {10$\bar{1}$0}, *r* {10$\bar{1}$1}, *o* {02$\bar{2}$1}.

Tourmaline is strikingly dichroic, especially in the brown and green varieties, the ordinary ray being more or less completely absorbed without change of colour. Thus brown tourmaline plates, which are cut so that the direction of the prism edges lies in their plane, transmit the extraordinary ray only; and accordingly before the invention of the nicol prism they were used for the production of plane-polarized light. The deep-green stones are likewise strongly absorbent, but the clear, green stones, which owe their tint to heat treatment, have practically no dichroism. The dichroic property has a most important bearing upon the proper direction for cutting tourmalines. Unless the stone be very light in tint, it must be cut so that a perpendicular to the table facet is at least nearly at right angles to the optic axis of the crystal, that is to the direction of the edges of the prism faces, because otherwise little light would emerge from the stone and it would appear dull and lifeless.

Tourmaline possesses a vitreous lustre. Material suitable for gem purposes is clear and transparent, but gradations or even abrupt changes of colour may be found. Occasionally it is distinctly fibrous in structure, and such stones, when suitably cut, will show chatoyancy. Tourmaline does not fluoresce when excited by ultra-violet rays. In its pyroelectric property it transcends all gemstones, and it can be strongly electrified by rubbing with a cloth; this property, although of little diagnostic value in the case of a cut stone, is of considerable scientific interest, because of the evidence that it adduces of the peculiar crystalline symmetry pertaining to its atomic arrangement. It will likewise display piezoelectricity.

The specific gravity varies within comparatively narrow limits for tourmalines of various colours, the ranges for particular tints being as follows: red, 3·01 to 3·06, pink stones usually having the lower values; green, 3·04 to 3·11; brown, 3·04 to 3·10; yellow (not a common tint), 3·10; blue, 3·05 to 3·11; black (these stones are almost opaque), 3·11 to 3·20.

The hardness of tourmaline is 7 to 7½ on Mohs's scale, the same as quartz. Tourmalines may therefore show signs of attrition, if worn in such a way as to be exposed to more or less constant rubbing, for instance in rings.

Like all coloured stones, tourmalines are usually brilliant-cut in front and step-cut at the back, but the top may also be step-cut; for ear-rings the drop form would probably be preferred. Stones with a fibrous structure would be cabochon-cut so as to display a cat's-eye effect.

Tourmaline is not difficult to discriminate from other gemstones which may resemble it in colour. Even at its highest its specific gravity is under the density of pure methylene iodide, and it will just float, whereas such species as corundum, zircon and garnet will sink. In range of refractive indices tourmaline and topaz overlap, but the much higher double refraction of the former is a certain diagnostic feature. In daylight by revolution of the stone on the refractometer the two coloured fringes can be clearly separated, whereas in the case of topaz there always appears to be only a single edge, although the fringe itself may seem to vary in width.

Tourmaline occurs as an accessory mineral in acid rocks, such as granite, particularly in pegmatites, and also in metamorphic rocks, such as schists and crystalline limestones; it has often resulted from the action upon the rocks of hot acid vapours emitted from below the earth's crust. The pink variety is generally associated with the lithium mica, lepidolite, and the groups of delicate pink crystals bespangling a background of greyish-white lepidolite are among the most beautiful of museum specimens.

Magnificent crystals of pink, blue and green tourmaline have been found in the neighbourhood of Sverdlovsk (Ekaterinburg), principally at Mursinsk, in the Urals, Russia, and fine examples of pink tourmaline have come from the Urulga River and other places near Nerchinsk, in Transbaikalia, Siberia.

Ceylon has provided the small yellow stones which were the original tourmaline; they are locally confused with zircon of a somewhat similar appearance found with them in the gem gravels. At the present time the tourmalines found are mostly brown, but sometimes they are yellowish-green; it is the latter which are wrongly styled 'Ceylon-peridot'. Most of the stones sold there as green tourmaline are really zircon. Pink tourmaline has been found in a decomposed granite at Maingnin, in Upper Burma, and a green tourmaline is known in the Northern Shan States, Siam. Tourmaline has occurred with sapphire and also with mica in Kashmir, India.

Beautiful crystals, red, blue and green, and often diversely coloured, have come from various parts, such as the lower Arassuahy, the Jequitinhonha and the upper Doce rivers, in the north-east of the State of Minas Gerais, in Brazil. The green stones when first introduced into Europe were wrongly named 'Brazilian-emerald'; it should be noted that the term is correctly used to-day for emeralds from Brazil.

Splendid gem material has been discovered in various parts of the United States, but principally from San Diego County in the south of the State of California, where in the pegmatite dykes near Pala and Mesa Grande a remarkable abundance of superb, transparent crystals, green, blue, yellow and red in colour, have been disclosed in company with kunzite and other lithium minerals. Two remarkable blue crystals were reported from here: the one measured 1¾ inches (45 mm.) in length and 1⅔ inches (42 mm.) across, and the other 2¼ inches (56 mm.) in length and 1 inch (24 mm.) across. Some interesting localities for tourmaline are in Maine: gorgeous pink and green crystals have come from Paris and Hebron, and deep-blue, green and lilac crystals from Auburn. Haddam, Connecticut, also is an important locality; from an albite quarry near the Connecticut River have come fine crystals, mostly green in colour but also pink and parti-coloured.

The deposits of Madagascar, arising from wind action, have provided an abundance of clear crystals of tourmaline, which for beauty will bear comparison with any found elsewhere. The range of colour is extensive, and includes shades of green, yellow, red, deep blue, amethyst and brown; even the rather rare colourless variety, achroite, is known from the island.

Tourmaline is included among the gemstones which have emanated from the pegmatites at Klein Spitzkopje in South-West Africa. The crystals are large and of good gem quality, and range in colour from blue through green to a pale yellowish-green; pink crystals have been found but are much less common.

Tourmaline is a comparatively common mineral and occurs, particularly in an opaque form, in many parts of the world, but few localities other than those already mentioned have supplied gem material of much importance. Mention, however, may be made of Elba, where pink, yellowish and green stones, often parti-coloured, have been found; sometimes the crystals are black at the top, and are then locally known as 'niggerheads'. The colourless variety, achroite, was first found in Switzerland. Tourmaline is among the many gemstone species which have been associated with diamond in the gravels of the Somabula forest of Southern Rhodesia.

XXVIII

OLIVINE

The lovely bottle-green gemstone, which from its delicate tint has earned from appreciative admirers the poetical soubriquet of the evening-emerald, has held a high place in public favour and graced much artistic jewellery for many years. As a gemstone it is usually known as peridot [1]; it is the precious variety of an important mineral species, which in science is called olivine or alternatively chrysolite. Olivine is much to be preferred as a name; chrysolite has in the course of the ages been bandied about from one mineral species to another, and to-day may be a synonym of the mineral, prehnite, as well as of olivine, or may even be the yellowish variety of chrysoberyl, and its use may therefore lead to confusion, unless the context happens to clarify the meaning.

When the green garnet, demantoid, from the Ural Mountains was first introduced the name olivine, unhappily, was proposed for it, with consequently a certain amount of confusion with the mineral species for which it had long been used; the name has now been discarded for the garnet by international agreement among the jewellers. The term 'oriental-chrysolite' has at times been wrongly employed for both the yellowish-green sapphire and the yellowish-green chrysoberyl. Other faulty terms are 'Brazilian-chrysolite' for chrysoberyl, 'aquamarine-chrysolite' for beryl and 'Saxony-chrysolite' for greenish-yellow topaz.

The most precious of the gem material is possessed of a true bottle-green colour in varying depths, the tint no doubt being due to the ferrous iron present. The sister stones tend to a less attractive olive-green colour, and are consequently held in much lower esteem. Olivine may display other colours, yellowish, brown or black, but the material

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[1] Peridot is generally pronounced with the final consonant silent and the final vowel long, as in the French form, péridot; in an alternative pronunciation the consonant is sounded and the vowel is short. The spelling, peridote, has been used from mistaken analogy with epidote, a mineral name which has traversed an entirely different etymological path.

is rarely transparent enough to be suitable for cutting purposes, and, moreover, the particular tint is even more rarely pleasing to the eye. Many of the pale yellow to deep brown gemstones, however, which were formerly supposed to be iron-rich olivine have recently been shown to be the newly-described species sinhalite (p. 351). Cut olivines of various tints are shown in natural colour on plate XX.

The name olivine was first proposed by Werner for the green variety found in basalts. Chrysolite comes from the Greek words χρυσός (golden) and λίθος (stone); Pliny used it for a golden-yellow stone,[1] which probably included our topaz and citrine (yellow quartz). Curiously enough, his topaz, which was a green stone and came from an island off Arabia, was probably our peridot. The word peridot is adapted from the French *péridot*, which in Old French was *peritot*; its origin is uncertain, and there appears to be no sound reason to trace it from an Arabic word, faridat (pearl or precious stone). Forsterite and fayalite, which are referred to in the next paragraph, were named, respectively, after J. Forster, a mineralogist, and Fayal, one of the Azores, from which place it was first described.

In chemical composition olivine is a magnesium-iron silicate, corresponding to the formula $(Mg,Fe)_2SiO_4$, and any gradation of composition may be expected between the end members: forsterite, magnesium silicate, Mg_2SiO_4, and fayalite, iron silicate, Fe_2SiO_4. The finest peridot is near the magnesium end; some iron, of course, is present, because to it is due the characteristic green colour, but its amount is only a small fraction, about a fifth, of that of the magnesium. As the amount of iron increases the colour becomes pale yellowish or brownish and the physical constants are higher.

Olivine crystallizes in the orthorhombic system of crystal symmetry, and the crystals, which usually display a large number of faces, are prismatic in form and generally somewhat flattened. It possesses two directions of pinacoidal cleavage at right angles, one rather distinct and the other less marked.

Since olivine belongs to the orthorhombic system, it possesses three principal indices of refraction, and its double refraction is therefore biaxial. Owing to the great variation possible in the percentage amount of iron present, the range in their values is considerable; for the least

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[1] 'The golden colour gave it the name chrysolite' (Colos appellavit chrysolithum aureus . . .), loc. cit., book 37, ch. 11. 'Aethiopia, which produces hyacinthos, produces chrysolithos also, a transparent stone with a refulgence like gold' (Hyacinthos Aethiopia mittit et chrysolithos, aureo fulgore translucentes), ibid., book 37, ch. 9.

and greatest of them it extends from 1·645 to 1·671 and from 1·683 to 1·708, the birefringence, however, remaining at about 0·038. For peridot the range is very much more restricted, extending only from 1·645 to 1·653 and from 1·683 to 1·690 for the least and greatest of the principal refractive indices respectively. In forsterite the mean principal index of refraction is nearer the least, and the sign of the double refraction is therefore positive, but with the addition of iron the mean moves towards the greatest, and for much olivine the sign becomes negative. Although olivine is surpassed by sphene in the extent of its birefringence, it easily surpasses all the ordinary gemstones in this respect with the one exception of zircon, and this character is sufficiently pronounced to be readily recognizable in a faceted stone by the apparent doubling of the opposite edges when they are viewed through the table facet (fig. 59). On the other hand, the dichroism is rather faint, one of the twin colours being only a little more yellowish than the other, but the phenomenon is more pronounced in the olive-tinted stones. The colour-dispersion is not large, amounting only to 0·020 for the *B–G* interval. Olivine displays a vitreous lustre. It has no fluorescence.

The specific gravity of olivine has a very wide range, extending from 3·2 for forsterite to 4·3 for fayalite approximately. For peridot it is much more restricted, and varies from 3·32 to 3·37 for pure green stones; brownish stones may, however, be as high as 3·50.

Olivine also is variable in hardness, the range extending from 6 to 7 on Mohs's scale of hardness. The best gem material is among the softer olivine, for which reason it should not be used in articles such as rings, where it is likely to be scratched, since the polish would soon deteriorate.

The usual form of cutting adopted for peridot is the step-cut, but it is often cut round or oval in shape, according to circumstances with brilliant-cut fronts.

The finest cut example of olivine is among the jewels that formerly belonged to the Russian Crown. A beautiful olive-green in colour, it is perfectly clear except for a few almost invisible cracks in the interior, which do not reach the surface. The large table facet, which is slightly convex, is surrounded by step facets; the cutting at the back of the stone is less usual, consisting of numerous irregular square facets. The shape is oblong, and the stone measures 5·2 by 3·5 cm. at the girdle and 1·05 cm. in thickness (2 by 1·4 by 0·4 inches); the weight is 192·75 metric carats. In bygone days it was mounted in a handsome setting, containing thirty brilliants. This magnificent olivine is now in the Diamond Treasury at Moscow.

Olivine is easily identified by means of a determination of its refractive indices, since its large birefringence separates it from gemstones with about the same refractivity. Even failing an optical test, its lower specific gravity discriminates it from chrysoberyl, the only gemstone with which it might be confused. It may be noted that ordinary bottle-glass has been known to be placed in streams, for instance in Ceylon, in order that in due course the water-worn fragments may be recovered and passed as olivine (peridot).

Olivine plays an exceedingly important rôle in the composition of various igneous rocks. It is an essential component of the rocks which are consequently called peridotites, one of them, dunite, being an almost pure olivine rock, and occurs in basic rocks like gabbros, basalts and dolerites; it is, moreover, one of the principal constituent minerals of the stony portion of meteorites. Except in the basalt lavas, olivine occurs in grains and rarely in well-shaped crystals.

Peridot which is large and transparent enough to be worth cutting for jewellery purposes has been derived mainly from the island Zebirget or Zeberged (St John's), on the west side of the Red Sea, about 50 miles (80 km.) from the port of Berenice in Egypt. In all probability it is the very island, mentioned by Pliny, where what he called topaz of a singular green colour was found (p. 316). Magnificent well-shaped crystals, a rich green in colour and beautifully clear, have been obtained from a peridotite rock which has been metamorphosed (altered) to a serpentine. * Some have been large enough to yield, when cut, stones weighing 20 to 30, and even as much as 80 carats; one rough mass came to light which weighed as much as 190 carats. The mines, which had been leased by the then Khedive of Egypt to a French syndicate, were closed down in 1914.

Various other localities are known for peridot, although none of them is important enough for exploitation. Pretty, light-green crystals have come from Toowoomba, Aubigny County, Queensland, and rather similar crystals have been found in the Bernardino Valley, near Mogok, in Upper Burma, not far from the ruby mines; another locality for pale-green crystals is Almeklovdalen, Söndmöre, Norway. Since the diamantiferous blue ground in the South African mines is a peridotite rock, it is not surprising that peridot is one of the minerals associated with diamond in it; unfortunately it is not found in large pieces. The prolific State of Minas Gerais in Brazil includes peridot, in crystals, among the many minerals that it has supplied, and rough material, without sign of crystal faces and with a less pleasing dark-yellowish shade of green, has come from some undefined locality in North America. Stones have

* dunite

also been found in the Congo. Peridot has also been found in Arizona, U.S.A., and on the beaches of Hawaii.

SINHALITE

For some years prior to 1952 a suspicion was growing in the minds of many gemmologists that a number of brown cut gemstones described as iron-rich olivines were misidentified. Mr B. W. Anderson and Mr C. J. Payne observed that the stones were unexpectedly pale in view of the supposed high iron content and that the β refractive index did not fit the established graph for olivine. Dr G. Switzer, examining a specimen in the collection of the United States National Museum in Washington, found that its X-ray powder photograph differed from that of olivine and was probably that of an undescribed species. Dr W. F. Foshag, in 1951, drew attention to a similar brown stone exhibited as olivine in the Mineral Gallery of the British Museum (Natural History). Further investigation by Dr G. F. Claringbull and Dr M. H. Hey[1] showed conclusively that most of the doubtful stones were indeed a new species, with the composition $MgAlBO_4$. Since the only localized specimens came from Ceylon, the name *sinhalite*, from Sinhala, the Sanskrit name for Ceylon, was chosen. In 1955 minute crystals of sinhalite were identified *in situ* in specimens of a contact metamorphosed limestone from Warren County, New York, confirming the suggested paragenesis of the Ceylon material.

Like olivine, sinhalite crystallizes in the orthorhombic system. Nothing is known of the crystal morphology, since all the known examples are cut stones (with the exception of the minute crystals mentioned above). The value of the least refractive index varies between 1·665 and 1·676 and that of the greatest between 1·705 and 1·712, with a birefringence from 0·036 to 0·038. These values correspond closely to those of an olivine with about 20 per cent fayalite content. In such an olivine, however, the β refractive index lies almost exactly half-way between α and γ, corresponding to an optic axial angle of almost 90°, whereas in sinhalite β lies much closer to γ, corresponding to a negative optic axial angle of only about 55°. This difference marks an important distinction between the new mineral and olivine. The pleochroism in the darker stones is α deeper brown, β green, γ lighter brown. The deeper colour of the darker stones presumably corresponds to a higher iron content, but insufficient analyses are available to substantiate this. A difference between the absorption-spectrum of

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[1] 'Sinhalite ($MgAlBO_4$), a new mineral,' *The Mineralogical Magazine*, 1952, vol. XXIX, pp. 841–9.

sinhalite and that of olivine is described on p. 109. The specific gravity, 3·47 to 3·50, is a little higher that that of green olivine but is, of course, well within the range displayed by the more iron-rich olivines. The hardness of sinhalite is not appreciably different from that of olivine.

The largest stone so far recorded appears to be one of 158 carats stated to be in the possession of W. E. Phillips, Los Angeles.

XXIX

ZIRCON

Zircon is a gemstone which even yet has not attained to a rank in the world of jewellery commensurate with its high qualities, a fate which may to some extent at least be set down to the fact that the names by which it has been known—zircon, jargoon and hyacinth (or jacinth)—have never become familiar to the world at large. Yet it can bear comparison with many better-known species in the variety of beautiful stones which it can boast. The colourless stones rival even diamond in splendour of brilliance and display of fire; the leaf-green stones possess a restful beauty that commends itself for service in many articles of jewellery; the bluish-green stones present a dazzling colour that is unique amongst precious stones; the deep-red stones, if somewhat sombre, are not without a grandeur of their own; and no other species can show such magnificent stones of a golden-yellow hue. Zircons of various kinds have long been appreciated in Ceylon and have passed into the hands of visitors to that sunny isle, who mostly had little idea what the stones were, but until the blue stones appeared on the market the species on the whole attracted very little attention. Zircons of various tints are shown in colour on plate I.

Various other names have been used throughout the ages for zircons of different colours, but there is no particular virtue in any of them, and they have been discarded. In the past it has been the practice to call the pale and yellow zircons, jargoon, the brown variety, zirconite and the reddish-brown stones, hyacinth. Colourless stones are not common in nature, and those that are seen were originally yellow or brown and have been deprived of their colour by the application of heat. The popular blue zircon and some of the golden-yellow stones are also the result of heating. In addition to the colourless and blue stones the most attractive varieties are the leaf-green, golden-yellow and red ones; other common colours are brown, yellowish-green and sky-blue (plate I 7, 11, 12 and 15).

The name of the species, zircon, was adopted from the French but what its actual origin may be is quite uncertain; it may have come from the Arabic *zarkùn* (cinnabar, vermilion), or the Persian *zargūn* (gold-coloured). Jargoon or, as it is sometimes spelt, jargon has the same origin and is really another form of zircon. Hyacinth, or jacinth, has come from the Latin *hyacinthus*, itself a transliterated form of the Greek word ὑάκινθος. In Greek mythology this was the name of the ill-fated youth beloved of Apollo, and the wild hyacinth was supposed to have sprung from the blood of the slain youth. The name was applied to stones of similar tint, which probably included the blue stones now called sapphire. Pliny compared hyacinth with amethyst rather to the disadvantage of the former:

> 'Very different from this stone (amethyst) is hyacinthos, though partaking of a colour that closely borders upon it. The great difference between them is, that the brilliant violet which is so refulgent in the amethystos is diluted in the other stone.' (Multum ab ea distat hyacinthos, tamen e vicino descendens. Differentia haec, quod ille emicans in amethysto fulgor violaceus, dilutus est in hyacintho.) Loc. cit., book 37, ch. 9.

As time went on, hyacinth was used generally for translucent corundum, and then, when sapphire and ruby came into use for the blue and red varieties, it was restricted to the other kinds, of which the yellow was the commonest. In the Middle Ages, when learning generally was at its nadir and little was known about the properties of minerals, hyacinth was loosely used for all yellow stones, and finally with increasing knowledge was assigned to the then commonest of them, the yellow zircons emanating from Ceylon. 'Starlight' (or 'starlite') is a fanciful name, which was coined for the blue zircons by G. F. Kunz.

It should be noted that the term hyacinth, or jacinth, has been wrongly used in connexion with other gemstones of a similar tint: 'oriental-hyacinth' (corundum), and hyacinth (garnet or spinel). Misleading and false terms are 'Matura-diamond' for colourless zircon, and 'Siam-aquamarine' for bluish-green zircon. Moreover, both colourless and blue synthetic spinel have been presented as synthetic zircon; although the artificial preparation of zircon has been successfully achieved, it has not been on a commercial scale, and considerable doubt may be felt whether it is likely to be, at least under existing conditions.

In chemical composition, zircon is comparatively simple, being a zirconium silicate, corresponding to the formula $ZrSiO_4$, but it invariably contains small amounts of many other elements, such as iron, copper, zinc, calcium, titanium and hafnium, together with rare-earth and radioactive elements. The presence of an unknown element in zircon was long suspected by chemists who had investigated its composition, but it was not until 1923 that hafnium (so called from Hafnia, an old name for Copenhagen) was separated from zirconium.

Zircon is unique among gemstones because of the remarkable range observed in its specific gravity and its refractivity, which is far too extensive to be explained by the small differences that have been discovered in the chemical composition or by possible cavities in examples of low specific gravity. Although it had long been known that the range in the specific gravity of zircons was peculiarly large, it was not until early this century that the existence of different types of zircon was revealed.[1] In some crystals the ions of zirconium, silicon and oxygen have the orderly and regular arrangement of a true crystalline structure. This structure is such that each zirconium ion is surrounded by eight nearest oxygen ions, but such an arrangement is not highly stable and in many crystals the orderly internal arrangement has partially or completely collapsed. A change of this kind, taking place without change of chemical composition, is called metamict[2] disintegration. It is now recognized that the breakdown of the original crystal structure is caused by alpha-particles discharged by radioactive elements within the crystal (some thorium commonly replaces a part of the zirconium, and the very characteristic absorption-spectra of many zircons appear to be due to the presence also of quadrivalent uranium ions). For present purposes we can thus distinguish three types of zircon:

I HIGH OR NORMAL ZIRCON

The high type comprises the definitely tetragonal crystals, such as the red ones from Espaly-Saint-Marcel. The crystals are generally very simple in form, the conspicuous faces being four in the prism zone and and four pyramid faces rising directly from them (fig. 127); occasionally the intermediate pyramid faces are present instead of the other set or in addition to them. It may be noted that in crystal form zircon closely resembles cassiterite (tinstone) and rutile. The specific gravity is high, its values ranging from 4·65 to 4·71, but usually approximating to the mean, 4·68. In view of the fact that the crystals belong to the tetragonal

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[1] The pioneer investigator was S. Stevanovič, whose work is described in his article, 'Beitrage zur Kenntnis der Mineralien der Zirkongruppe,' *Zeitschrift für Krystallographie und Mineralogie*, 1903, vol. 37, pp. 247–52.

[2] The term metamict was originally introduced in 1893 by Waldemar Christofer Brögger (1851–1940). The word is compounded from two Greek words μετά (among) and μικτός (mixed).

system, the character of the refraction is uniaxial. The birefringence is extremely high, varying from 0·058 to 0·059, and surpasses that of any ordinary gemstone with the exception of sphene, with the consequence that the apparent doubling of certain of the opposite edges of the facets, when viewed through the table facet, is very evident. The values of the ordinary refractive index range from 1·924 to 1·933 and those of the extraordinary refractive index from 1·983 to 1·992. Since the latter is greater than the former, the sign of the double refraction is positive. The physical properties remain unaffected by the application of heat except that the colour may be altered or even driven off altogether. The high is slightly harder than the low type (see below), about $7\frac{1}{4}$ on Mohs's scale.

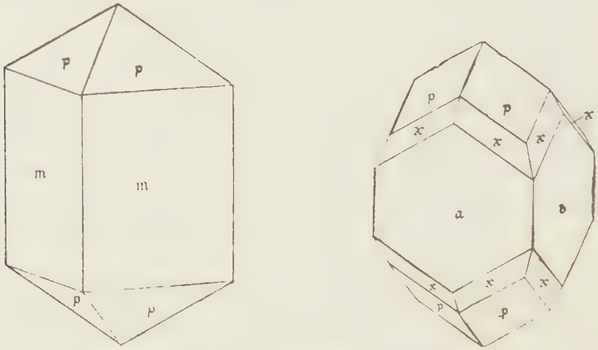

FIG. 127.—Crystals of zircon.

The crystals possess a poor cleavage parallel to the common prism faces and a still poorer one parallel to the more usual pyramid faces. The most usual colours are honey-yellow, light-green, blue and red.

The high type is the completely crystallized zirconium silicate, and corresponds to the true zircon; it may therefore fittingly be termed normal zircon.

2 LOW OR METAMICT ZIRCON

This type, which is rare, has been found in Ceylon in the form of rolled pebbles showing no trace of crystal form. Its specific gravity and refractive indices are low, varying from 3·94 to 4·10 and from 1·78 to 1·84 respectively. The refraction is very nearly but never quite single in character; some double refraction, though very small, is always present and sometimes the double refraction is slightly biaxial. Its hardness is lower than that of the high type, and is expressed by the symbol, 6, on Mohs's scale.

The low type of zircon is composed of amorphous silica, SiO_2, and amorphous, or alternatively microcrystalline, zirconia, ZrO_2. On some examples the effect of heating is to cause a slight expansion of the structure with the result that the specific gravity falls about 6 units and the refractive index about 35 units in the third place of decimals. At the same time the colour changes, for instance, from brown to green, and the degree of translucency is improved. The feeble birefringence remains unaltered. Other examples, however, behave quite contrariwise, and on being heated to 1450° C. become transformed into the high type.

The low type of zircon is always green in colour, the tint varying from leaf-green to dirty brownish-green.

This type of zircon may conveniently be termed low zircon as a reminder that its values for the refractive indices and specific gravity are appreciably lower than for the other two types. It is called metamict because of its amorphous character.

3 INTERMEDIATE ZIRCON

Although the intermediate type ranges in specific gravity from the high to the low type, it differs from the latter by the possession of a measurable amount of double refraction, the minimum of which is about 0·010. The birefringence is normally uniaxial but occasionally, no doubt because of local strain, may be biaxial in character. The minimum values of the ordinary and extraordinary refractive indices are 1·84 and 1·85. The minimum value of the specific gravity is about 4·10, and examples may be found with values lying between this minimum and the maximum, which is the value of the specific gravity possessed by the high type. A corresponding gradation characterizes the refractivity; as the specific gravity increases in value, so do the refractive indices and the birefringence until they merge in those possessed by the high type.

The effect of heating, at 1450° C., the intermediate type, at whatever stage it may be, is to convert it into the high type.

Stones belonging to the intermediate type frequently display a marked zonal or banded structure. Their predominant colour is green, just as in the low type, but at the upper end of the series, where the specific gravity exceeds 4·50, shades of yellow and brown, tending towards green, may be seen. This type may be considered to be composed partly of the crystallized zirconium silicate, the high type, and partly of the separate oxides, the low type, and the physical properties depend upon the proportion of the high type to the low type.

Material of this type which is of gem quality comes only from Ceylon; that from other places is not suitable for jewellery purposes.

Zircon is favoured with a colour-dispersion, amounting to 0·039 for the *B–G* interval, which is only slightly under that of diamond, and consequently colourless stones when suitably cut display considerable fire. Since at the same time the lustre is adamantine, the similarity of a colourless zircon to a diamond at a casual glance is close.

It is a peculiarity of zircon that it sometimes exhibits in the spectroscope a striking absorption-spectrum (plates I and XXII), which is ascribed to the presence of uranium.[1] When fully developed, it is far more spectacular than that of any other gemstone. The principal bands are centred at the following positions expressed in the Ångström units of wave-length: 6910 (strong), 6830 and 6625 (moderate), 6535 (very strong), 6210 and 6150 (moderately weak), 5895, 5625 and 5375 (strong), 5160 (moderate), 4840 and 4325 (strong). As many as thirty-six bands have been observed in the case of greenish-brown stones from Burma. The most important of them are those mentioned above. The Ceylon stones exhibit a smaller range of bands, at the most only fourteen, which include the ones mentioned. The strongest and most persistent band is the one centred at 6535, and if seen suffices to identify the stone as zircon with perfect certainty, a point of some importance since the refractive indices of zircon are too high to be measured on a refractometer of the usual type. It must not be overlooked, however, that many zircons, especially those red in colour, exhibit no absorption-bands at all, and frequently even the conspicuous one mentioned above may be very faint and invisible to all but the most practised eyes.

According to Church, who made a lifelong study of zircon, the green and yellowish stones of the low type emit a brilliant orange light while being ground on a copper wheel charged with diamond dust, the golden stones of the intermediate type glow with a fine orange incandescence in the flame of a bunsen gas-burner; the latter phenomenon was supposed to be due to the presence of thorium. Zircon is always brittle, and especially so after heat treatment.

Colourless zircons are mostly cut as brilliants; the coloured stones lend themselves to various treatments according to their purpose, but the mixed (brilliant in front and step at the back) is the most usual form of cutting.

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[1] This phenomenon was first remarked by Sir Arthur Church (p. 102).

Zircon is in demand not merely in jewellery but also in industry, principally as the source of zirconium, the metal, and zirconia, the oxide. The metal serves a useful purpose in the manufacture of steel by assisting in the removal of oxides and nitrides. The oxide finds many uses: as a refractory substance for lining furnaces, as an ingredient in enamels, and as an abrasive. Zircon itself is sometimes used as a refractory substance.

Sir Arthur Church (p. 20) devoted much of his leisure during many years to collecting cut stones, and paid particular attention to zircon. In consequence, his collection, which is now in the British Museum (Natural History), contains a marvellous series of zircons, of various shades of colour.

The high refraction of zircon puts it beyond the reach of an ordinary refractometer. A negative determination with a refractometer, or, in other words, the fact that the refractivity of the stone under test is higher than the limit of the scale of the instrument, is of great value, since it rules out all but a restricted number of gemstones; these are chiefly diamond, garnet (almandine and demantoid) and sphene. Many zircons are identified readily by their characteristic absorption-spectra. Yellow stones usually show all the strongest lines, distinguishing them from sphene and from yellow diamond. Even in colourless stones a narrow line at 6535 and a fainter one at 6590 are visible. Green zircons always show a distinctive spectrum, though in partially metamict stones the lines are less sharp and a completely metamict stone may show only a diffuse band about 6530 in the red. Some red zircons, however, show virtually no spectrum; almandine garnet, with which they might be confused, displays a characteristic spectrum and is isotropic whereas the zircons, being invariably of the high type, are always strongly birefringent. Colourless zircon, though possessed of adamantine lustre and considerable fire, is easily distinguishable from diamond by its inferior hardness, double refraction (which is large enough to provide apparent duplication of certain of the opposite edges of a cut stone, when viewed through the table facet) and lower refractivity (which enables a much larger portion of the light falling upon the front of a brilliant-cut stone to escape at the back); moreover, diamond floats in Clerici solution. The skilled eye cannot mistake the green garnet, demantoid, for zircon, so different are the shades of colour; any doubt would be resolved by the lower specific gravity of demantoid.

Zircon is a far from rare mineral, and is a constituent of many igneous rocks, such as granite and syenite, and metamorphic (altered) rocks, such as crystalline limestone and gneiss. It strongly resists alteration and survives therefore in the gravels and other deposits which result from the breaking down of the parent rocks.

On the other hand, material suitable for jewellery purposes has come only from a very few areas, of which Ceylon is by far the most important. Here in the rich gravels, which have proved so prolific in gemstones, have been found zircons of practically every tint that this gemstone has succeeded in assuming, including the reddish-brown (hyacinth), and yellow and green of various shades. Although most colourless zircon is the result of heating, it is possible that some may be a natural product of the area near Matara (Matturai) in the extreme south of the island; all colourless zircons are locally known by the misnomer, 'Matura-diamond' or 'Matara-diamond'. The term, hyacinth, is misused to include the reddish garnets of a similar hue, which are found in the same gravels as the zircons. Many of the zircons are of the low or the intermediate type.

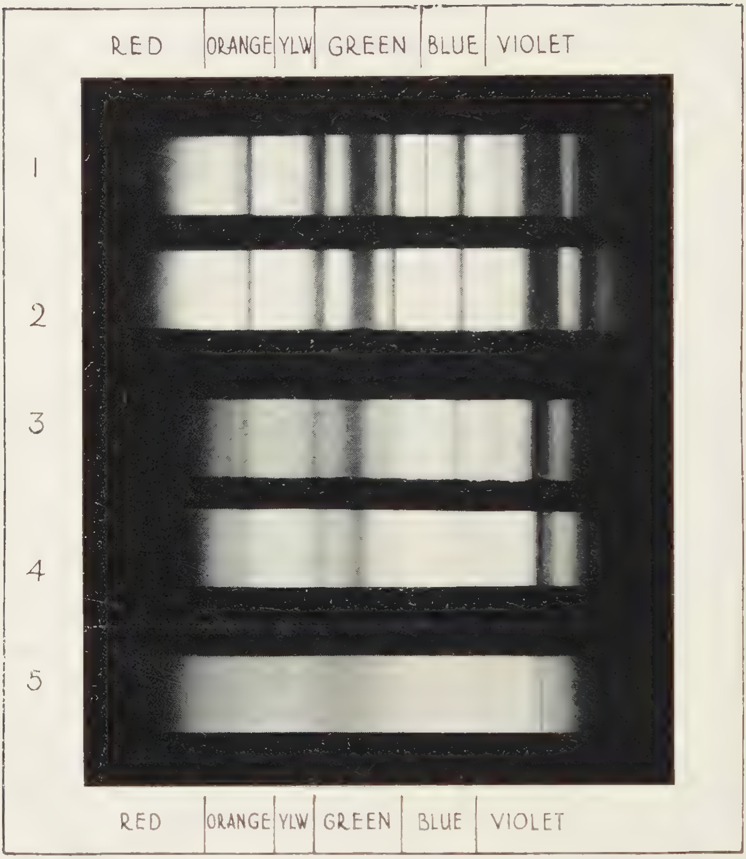
It is largely thanks to the beautiful blue stones that zircon became known to the public at large. As has already been remarked, this shade of colour is not found in nature, and has been evolved in certain hyacinths by the application of heat. Indeed, all the blue, golden-yellow and colourless stones which are so popular in jewellery to-day owe their colour to the heat treatment of reddish-brown material from Indo-China. In general, it turns blue, if heated in a reducing flame, that is, one in which the supply of air is insufficient for complete combustion, and colourless or golden-yellow, if heated in air. Unhappily these popular stones are prone to discolour in course of time, especially the blue ones; the colourless stones are more constant, and the golden-yellow ones appear to be stable. It should be observed that, inasmuch as the material is invariably worked at Bangkok, in Siam, the stones are consequently wrongly known as 'Siam-zircon', and worse still, if blue in colour, are misnamed 'Siam-aquamarine'.

Well-shaped, though small, crystals of a brownish-red or a deep-red colour have been found at Espaly-Saint-Marcel, near Le Puy, Haute-Loire, France and similar crystals, but of rather yellowish-red colour, from the gold-producing regions of the Ural Mountains, Russia. Remarkably fine crystals, red in colour, have been produced at Mudgee, New South Wales and in Madagascar also. Yellowish-brown zircons, of a rather poor quality, are among the associates of the diamond at the South African mines.

1. Diamond-concentrating machines

2. Diamond-sorting machines

XXI



(*Reprinted from* The Gemmologist)

1. Blue (heat-treated) stone
2, 3. Different exposures, Ceylon stone
4, 5. Different exposures, Burma stone

XXII. ZIRCON ABSORPTION-SPECTRA

XXX

CHRYSOBERYL

Chrysoberyl is a gemstone which has at times enjoyed a passing popularity on account of the excellent cat's-eyes provided by the cloudy stones, and in the chameleon-like form of alexandrite it meets with a steadier, though still limited, demand. In ordinary jewellery it is seldom to be found, although its considerable hardness eminently befits it for all such purposes.

The term cat's-eye was originally applied to the chatoyant variety of chrysoberyl, but is no longer restricted to it. Other species, for instance quartz and tourmaline, produce examples with a fibrous structure which shows a similar effect; to avoid misconception, such stones should be termed quartz cat's-eye or tourmaline cat's-eye, as the case may be. Alexandrite is in appearance so markedly different from the other kinds of chrysoberyl that its essential similarity to them is at first sight almost incredible. The dull fires that seem to glow within them in ordinary daylight, and the curious change in colour, which affects them when seen by artificial illumination, add a touch of mystery to these dark stones. The Russian alexandrites incline to the bluish shade of green, whereas the Ceylon stones are usually a deep olive-green in colour. It should be stressed that there is no such stone as synthetic alexandrite; those that have been submitted to the market under that guise were in reality synthetic corundum or synthetic spinel. The passing tourist should be very suspicious of the wonderful bargain in alexandrite that may be offered him at Colombo; if he were to succumb, he would gain a pleasing stone, but at a price far in excess of what such synthetic stones command in London. Cymophane is a term which was introduced for chrysoberyl cat's-eyes because of the opalescence that they display. It is preferable, however, to describe chatoyant stones by the specific name in all cases. The pale-green chrysoberyls were at one time known as chrysolite, but this is the accepted mineralogical term for a part of the olivine family.

If chrysoberyls corresponded precisely in composition to their chemical formula, they would be clear and colourless. Such examples are known, but they are exceedingly rare; not that there would be any demand for them, since their moderate refractive power and small colour-dispersion ill fit them to compete with diamond, zircon or even white sapphire. Chrysoberyls display all shades of green from pale yellowish to brownish, and alexandrites are a bluish or grass-green, or a deep olive-green.

The word chrysoberyl is derived from two Greek words, χρυσός (golden) and βήρυλλος (beryl), and etymologically more aptly defines the lighter-coloured stones, which were, indeed, at one time, the only examples known; chrysolite, from χρυσός (golden) and λίθος (stone), has much the same significance. Originally chrysoberyl was probably a variety of beryl, and chrysolite was topaz. Cymophane, from κῦμα (wave) and ψαίνειν (to appear), refers to the peculiar opalescence characteristic of the chrysoberyl cat's-eye (plate XVII, 7). Alexandrite was named after Alexander II, Czar of Russia, on whose birthday it was first discovered. That circumstance, coupled with its display of the then national colours and its at one time restriction to the Urals, rendered it very popular in Russia in the days of the bygone régime. A yellowish-green chrysoberyl, the Hope chrysoberyl, also is shown in natural colour on plate XVII, 10.

In composition chrysoberyl is a beryllium-aluminium oxide corresponding to the formula $BeAl_2O_4$. It almost invariably contains some ferric iron and chromium in place of aluminium, and ferrous iron in place of beryllium; titanium is sometimes present. The various tints assumed by chrysoberyl are caused entirely by these accessory constituents. The one most commonly seen, a pale yellowish-green, results from the presence of iron, and chromium may be held responsible for the shades of green. Beryllium is one of the less common elements; other gemstones containing it are beryl, which gave it its name, and a few species, which are seldom cut except as curios, such as phenakite, euclase, beryllonite and hambergite.

The chemical formula prompts comparison with spinel, but in fact the structures of the two species are quite different and give rise to different crystal morphology and other physical properties. The structure of chrysoberyl closely resembles that of olivine, and like olivine chrysoberyl crystallizes in the orthorhombic system, in rather dull, prismatic crystals (fig. 128 (1)). It happens that the zone including *c* (001) and *b* (010) is very nearly hexagonal, the angles (001 : 011) and (001 : 021) being 30° 7′ and 60° 7′ respectively. The face (021) is rare, but repeated twinning about its normal is common, especially in the alexandrite variety, the result being a stellate appearance and a simulation of hexagonal symmetry (fig. 128 (2)). The striated face (100) in the figure is common to all the constituent individuals, and the pairs of faces *o* (111) are nearly but not quite coplanar; the fact that such crystals are complex twins and not simple is revealed by the clefts visible in the edges of the pseudo-hexagon.

In keeping with its crystal symmetry chrysoberyl is biaxial. The least and greatest refractive indices have values ranging between 1·741 and 1·750 and between 1·749 and 1·759, the amount of double refraction varying from 0·008 to 0·009. The mean exceeds the least principal refractive index by only one unit in the third place of decimals; the sign of the double refraction is therefore positive. The optic axial angle $2V$ is small enough to yield a good optic picture. The lowest values of the refractive indices correspond to the colourless stones; the brown stones have slightly higher refraction than the yellow stones. The colour-dispersion B–G is small, amounting only to 0·015; chrysoberyl is therefore lacking in fire.

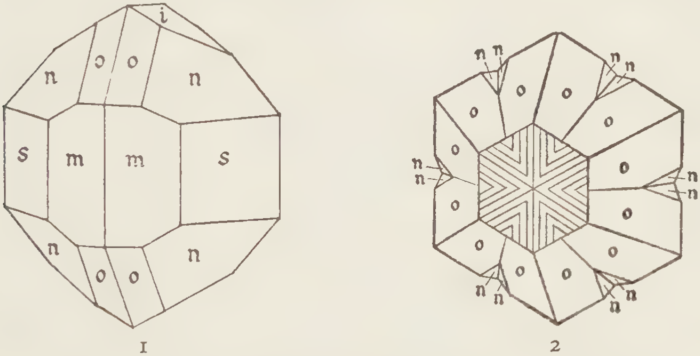


FIG. 128.—Chrysoberyl crystals: (1) simple, (2) twinned.

Alexandrite possesses remarkable pleochroism, the colours corresponding to the least, mean and greatest of the principal refractive indices being columbine-red, orange-yellow and emerald-green respectively; all three tints are in marked contrast, particularly the first and third, and no phenomenon is more striking in gemstones than the red and green gleams emitted from a faceted alexandrite, when light has traversed the stone in certain directions. (The yellow chrysoberyls are also dichroic, but to nothing like the same degree, the phenomenon merely taking the form of variation in the intrinsic colour.) If a stone be viewed by means of a spectroscope, an important difference will be noticed between the spectra corresponding to the direction of the least and greatest refractive indices. A broad absorption gap, which begins in the green, extends much further towards the red in the latter instance, and explains why this ray appears green and the other red. The other bands (p. 106) are much the same for both rays. This spectrum is due to the presence of chromium. The yellow and brown varieties display a strong band at 4440 Å in the blue-violet, which is stronger in the former; it is due to the presence of iron in the ferric state. The gap in the spectrum of alexandrite, which has been referred to, includes the part of the spectrum to which our eyes are most sensitive, and to all intents and purposes the light emitted by an alexandrite is a mixture of red and green with in certain directions a greater tendency towards the red. The balance is so nice that the stone appears green in daylight but reddish in artificial light, in which the red end of the spectrum is relatively stronger. A fine Ceylon alexandrite in the British Museum (Natural History), as seen in daylight and artificial light, is shown in natural size and colour on plate XVII, 1 and 3. The lustre of chrysoberyl is vitreous. Certain examples contain a multitude of microscopic channels, which are arranged parallel to the crystallographic axis corresponding to the direction of least refractive index. When such a stone is cabochon-cut so that the perpendicular to the rounded surface is at right angles to the channels, a broadish band of light is visible, running across the curved top of the stone; this phenomenon is suggestive of the pupil of the eye of a cat, and such stones are consequently called cat's-eyes (plate XVII, 7). Since the channels are usually hollow, an opalescent effect is produced, which is absent in the quartz cat's-eye.

In examples of gem quality, chrysoberyl shows very little variation in specific gravity, the range extending only from 3·70 to 3·73. As in the case of the refractivity the low value, 3·70, corresponds to the nearly pure, colourless material.

In hardness, chrysoberyl ranks between corundum and spinel (also topaz), and is assigned the symbol 8½, on Mohs's scale.

Chrysoberyl possesses several directions of cleavage of very moderate quality. There is no likelihood of flaws developing in the course of ordinary wear.

Cat's-eyes are always cabochon-cut, but otherwise chrysoberyl is usually step-cut or brilliant-cut.

Alexandrite is by far the most valuable variety of chrysoberyl.

The British Museum (Natural History) contains besides the Hope chrysoberyl, which has already been described (p. 253), another of a slightly darker shade of yellowish-green, which weighs 29·35 carats, and two exceptionally fine alexandrites from Ceylon, which weigh 43 and 27·5 carats respectively; the larger of the latter is the alexandrite represented on plate XVII.

The Hope collection contained an enormous cat's-eye,[1] nearly a hemisphere in shape with a diameter of about 1½ inches (37 mm.), which was so cut as to show a picture of an altar surmounted by a torch.

No synthetic chrysoberyl is as yet known. The so-called synthetic alexandrite (p. 200) is really either a synthetic corundum, which is gifted with a similar peculiar shade of purple that turns redder in artificial light or a synthetic spinel, which is a better green in colour, but is, of course, devoid of dichroism. Chrysoberyl, when colourless or yellow, might be mistaken for white or yellow sapphire. A test with the refractometer easily distinguishes them. Chrysoberyl has perceptibly lower refractivity; moreover, the shadow-edge corresponding to the lower refractive index as seen in the field of the instrument always appears constant in position as the stone is rotated, since the mean is so near the least principal refractive index in value, whereas in the case of corundum, which has negative birefringence, it is the other shadow-edge which never moves. Confirmatory tests are the stronger dichroism and the lower specific gravity of chrysoberyl.

Practically all chrysoberyl suitable for gem purposes has emanated from alluvial deposits. The most important locality for the yellowish chrysoberyl has long been the rich mineral district of Minas Novas in Minas Gerais, Brazil, where it has been found, usually in the form of pebbles, with several other gemstones: topaz, garnet, tourmaline, euclase and amethyst. It has also turned up in São Paulo and Espirito Santo. The stones are usually imperfectly transparent and inclined to be cloudy in texture. Ceylon surpasses Brazil in the remarkable range of differently tinted chrysoberyls which have been produced by the prolific gem gravels in the southern part of the island. Every kind of the ordinary yellow chrysoberyl and of cat's-eye is known there, but what distinguishes Ceylon most is the dark alexandrite which is peculiar to it. The Russian alexandrite is bluer in tint and therefore to some tastes more attractive, but it is not so clear or so large. The Ceylon stones may attain to as much as 20 carats in weight. The Russian alexandrite is one of the gemstones associated with emerald at the mines on the Tokovaya River in the Ural Mountains. Other places where chrysoberyl has come to light are Drew Hill, Golden, Jefferson County, Colorado, Haddam, Connecticut and Greenfield, New York, in the United States, the diamantiferous gravels in Somabula Forest in Southern Rhodesia and Madagascar. Clear, colourless chrysoberyl is known from Mogok, Upper Burma.

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[1] Numbered 9 in the Catalogue by B. Hertz, London, August, 1839.

XXXI

QUARTZ

Although quartz is by far the commonest and in its crystal form the most easily recognizable of minerals, it is by no means to be despised as a gemstone. No other species supplies stones of such a marvellous purple shade. The yellow quartz can vie with topaz in the beauty of the yellow stones that it provides; indeed, so close is the resemblance that for long they were confused together, and it is only within recent years that in the authoritative international nomenclature the use of topaz for the yellow quartz has been forbidden. The familiar colourless quartz known as rock-crystal may be so lustrous and water-clear that the glittering stones aspire locally to the title of diamond in spite of their comparative lack of fire; although such misnaming can deceive only the very ignorant, it is not a practice to be encouraged. For all purposes for which a purple, yellow or smoky stone is required, quartz will serve admirably; it is durable and hard enough to withstand ordinary wear, and it has the merit, or possibly to some minds the drawback, of being moderate in price. Despite its want of fire it might replace paste, with considerable advantage from the point of view of durability, in some articles of jewellery. Further, quartz is sometimes sufficiently fibrous in structure to furnish excellent cat's-eyes, which, though not so opalescent as the chrysoberyl cat's eyes, will bear comparison with them; a particular kind known as tiger's-eye is peculiar to quartz.

When quartz is pure in composition, it is entirely devoid of colour and almost water-clear in its limpidity. It is this kind which, when first discovered in the Alps, was believed to be a form of frozen water and therefore called crystal, or its equivalent in the language used, from the Greek word *κρύος* (ice); it is still known as rock-crystal. It has already been remarked that these sparkling stones, when cut, are locally called diamond. Thus, in this country, terms such as 'Cornish' or 'Bristol-diamond' have been in use, and abroad there is a large number of them, for instance 'Alaska-diamond', 'Arkansas-diamond', and 'Bohemian-diamond'. Terms such as these are misleading, and have now wisely been abandoned by responsible jewellers. The name quartz appears to have been first used by the miners in the Erzgebirge on the borders of Saxony and Bohemia. In olden days the essential identity of what was then called crystal and the shapeless silica mineral in cross veins was not realized, and it may reasonably be conjectured that in the beginning the latter was known as *Querkluftertz*, which became contracted to *Querertz* and ultimately to *Quartz*, in modern German *Quarz*.

The superb purple or bluish-violet colour of amethyst varies considerably in depth, and at one time jewellers were inclined to distinguish the more deeply coloured stones by the appellation, 'oriental-amethyst'; a custom to which there was the grave objection that the term was already in use for the violet sapphire (corundum), and less commonly for the violet spinel. The risk of confusion, however, has now been obviated by the abolition of all terms involving the word, oriental, in gemstone nomenclature. Since manganese, titanium and iron have been detected in the chemical analysis of amethysts, it was at first supposed that the tinctorial agent was manganese or possibly titanium; but a study of the absorption-spectra suggests that iron in a colloidal form may really be responsible. The name of the variety amethyst comes from the Greek word ἀμέθυστος (not-drunken), which was originally given to it from the curious but mistaken belief that the wearer became immune against the usual penalty of unrestrained indulgence in potent liquors. Pliny advances the alternative suggestion that its colour approaches, but does not quite reach that of wine:

> 'The name which these stones bear originates, it is said, in the peculiar tint of their brilliancy, which, after closely approaching the colour of wine, passes off into a violet without being fully pronounced; or else, according to some authorities, in the fact that in their purple there is something that falls short of a fiery colour, the tints fading off and inclining to the colour of wine." (Causam nominis afferunt, quod usque ad vini colorem accedens, prius quam eum degustet, in violam desinit; fulgorque quidam in illa purpurae non ex toto igneus, sed in vini colorem deficiens). Loc. cit., book 37, ch. 9.

Citrine is the correct name for the yellow variety of quartz. It is an adaptation of the French word *citron* (lemon), and was given to it because of the resemblance in colour of certain kinds to that fruit. Until, however, the characters of minerals became better known, the yellow quartz was confused with the yellow topaz. Although the true topaz has long been firmly established as a mineral species, jewellers even now still persist in calling the yellow quartz 'topaz' and distinguish the true topaz by the prefix, Brazilian. The confusion has thereby been intensified rather than relieved, because both the yellow quartz and the yellow topaz have been found in abundance in Brazil. Other names, which have been proposed for the yellow quartz, are 'occidental', 'Spanish' and 'false' topaz. All these unsuitable terms should be swept away and no longer recognized.

Cairngorm (the original and more correct name is cairngorm stone) is quartz of a brownish or smoky shade of yellow. It was so called because many examples of this variety of quartz were found in the Cairngorm Mountains, Scotland. Cairngorm is a slightly altered form of the Gaelic word *carngorm* (blue cairn). It has been miscalled 'Scottish topaz'. Stones, in which the colour has deepened to a definitely smoky shade of brown, are known as smoky-quartz. Morion is the term given to smoky-brown or blackish stones. The term is corrupted from *mormorion*. Various suggestions have been put forward to account for these yellow and brown colours. It appears probable that they may be due to structural defects rather than to the presence of impurities.

Sometimes quartz has crystallized around previously formed minerals, which are therefore included within it. Sometimes it encloses a massive, light-coloured, fibrous mineral, and produces then a chatoyant effect; when cabochon-cut in the correct orientation, such stones display a fine cat's-eye effect. Since the agent is a solid and not a hollow channel as in a chrysoberyl, the quartz cat's-eye, as it should for distinction be called, has not the opalescence of the chrysoberyl cat's-eye. When the enclosed mineral is crocidolite, an asbestos, the original blue colour of which has been changed by oxidation to a fine golden-brown, the stones are known as tiger's-eye or tiger-eye. Occasionally the crocidolite has been silicified without alteration of the blue colour; it has then been known as 'sapphire-quartz', 'azure-quartz' or 'siderite'. All three names are confusing and unsatisfactory and should be abandoned. An alternative and more satisfactory name is falcon's-eye. Prase, or mother-of-emerald, as it was sometimes called because it was supposed to be the mother-rock of emerald, is a quartz which is coloured a leek-green by actinolite (calcium–magnesium silicate) fibres in the interior; the word prase is derived from the Greek πράσον (leek). Slender, hair-like crystals of rutile, the so-called *flèches d'amour*, are sometimes seen included in clear, transparent quartz, which is then known as rutilated-quartz. Occasionally the included substance consists of scales of mica, haematite or other flaky mineral, and the result is a vivid spangled appearance which is reminiscent of a glass, containing copper crystals, which was called aventurine; this variety of quartz was given the same name.

Aventurine, or incorrectly avanturine, is derived from the Italian word *avventura* (chance); the effect is supposed to have been first noticed when a quantity of copper filings fell into a pot of molten glass in a glass-factory at Murano, near Venice.

Rose-quartz, which, as its name implies, is rose-red or pink in colour, owes its beautiful tint to manganese, and is apt to lose it on exposure to strong sunlight. This variety of quartz rarely displays crystal faces, and at the best is only partially translucent and is more or less riddled with cracks. Asterism is commonly present.

In milky-quartz the structure is so hazy and semi-opaque as to suggest milk in appearance. Rainbow-quartz, or iris, is a quartz which contains cracks, and owes its name to the colour effect resulting from the interference of light falling upon them. The cracks can be artificially produced by heating the stone and suddenly cooling it by plunging it into water, and in such instances the effect may be heightened by forcing colouring matter into the cracks.

Cut specimens of amethyst, citrine, smoky-quartz, tiger's-eye and quartz cat's-eye are shown in natural colour on plate XVII.

Quartz ranks with corundum in being next to diamond the simplest of the gemstones in chemical composition, being merely silicon oxide or silica, corresponding to the formula SiO_2. Two other forms of crystallized silica are known in nature: tridymite, which is the stable form at ordinary atmospheric pressures at temperatures between 870° and 1470° C., and cristobalite, which is the stable form at higher temperatures. Both species are rare, and neither provides material even remotely suitable for gem purposes.

Quartz crystallizes in the trigonal trapezohedral class of the trigonal system (p. 37). Simple crystals often show apparent hexagonal symmetry (fig. 129 (2)), but if the faces s are developed (fig. 129 (1) and (3)) their appearance on alternate coigns only is an indication that the true symmetry is trigonal. Development of faces of the general form x proves the absence of any planes of symmetry; in addition to the vertical trigonal axis there are present only three horizontal digonal axes emerging through the prism edges. Simulation of hexagonal symmetry is also partly due to the frequency with which quartz is twinned about a pair of prism-faces, the two individual crystals interpenetrating and appearing like one. Twinning about an intermediate pair of prism-faces is also common, the two individual crystals usually interpenetrating; it is twinning of this kind that accounts for the alternate amethystine and colourless triangular sectors often seen in a section of a crystal cut at right angles to the trigonal axis. There is yet a third type of twinning in quartz, in which the trigonal axes of the two individuals cross at nearly a right angle (84° 33′); the individuals are separate and in contact, and the twinning is therefore more easily recognizable. Interpenetrant twins are so common that even apparently simple crystals, when searchingly examined, are found to be twinned. To the twinning are due the rippled fracture and the feathery inclusions so characteristic of amethyst.

The X-ray study of quartz has confirmed the conclusion, already deduced from the morphological and optical characters, that the structure is helical or spiral in arrangement, that is, like a screw, and in accordance with such an arrangement is of two kinds: right-handed and left-handed (fig. 129). Amethyst is, in fact, invariably composed of separate twinned individuals, which are alternately right-handed and left-handed; in some remarkable crystals the section cut at right angles to the prism edge will be found to show triangular sectors, which are alternately of different hands and of different colours: purple and white.

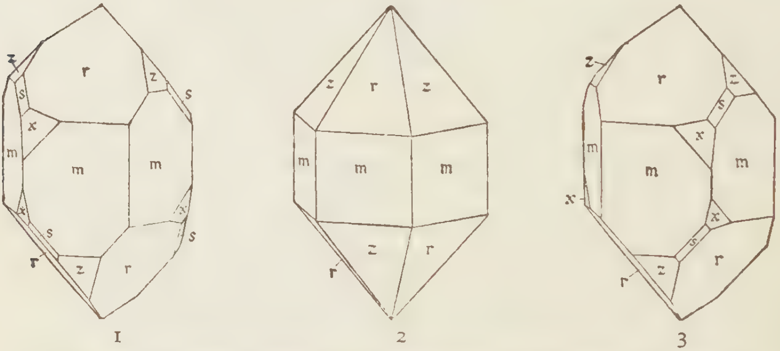


FIG. 129.—Quartz crystals: (1) left-handed, (2) simple, (3) right-handed; forms $m\ \{10\bar{1}0\}$, $r\ \{10\bar{1}1\}$, $z\ \{01\bar{1}1\}$, $s\ \{11\bar{2}1\}$, $x\ \{51\bar{6}1\}$.

In harmony with its crystal symmetry, quartz possesses uniaxial double refraction and therefore two principal refractive indices: the ordinary and the extraordinary. The value of the former is 1·544 and of the latter 1·553, and the maximum amount of double refraction is 0·009. It is evidence of the purity of the chemical composition of transparent material that hardly any variation from these values has been observed; for certain coloured stones there is a slight rise to 1·545 and 1·554 respectively.

Small as the amount of double refraction is, it is large enough to permit of the apparent doubling of certain of the opposite edges of a faceted stone to be perceptible when carefully viewed with a lens through the table facet. Since the extraordinary is greater than the ordinary index, the sign of the double refraction is positive. The colour-dispersion *B*–*G* is low, amounting to 0·013 only, and quartz is therefore lacking in fire; ordinary window-glass has slightly greater dispersion. Quartz has a good vitreous lustre, and rock-crystal, if cut in brilliant form, scintillates attractively, but emits no coloured gleams. The deep-coloured varieties show a distinct dichroism, mainly by a variation in the depth of tint.

In keeping with the spiral character of its structure, quartz is possessed of the remarkable property of rotating the plane of polarization of a beam of light traversing a section, cut at right angles to the prism edge, the angular direction being to the right or to the left with the orientation of the path of the beam in accordance with the right-handed and left-handed character of the structure. The amount of rotation varies with the thickness of the section and the wave-length. The variation increases very rapidly while the wave-length decreases as is shown below for the angle of rotation for a thickness of 1 millimetre corresponding to different wave-lengths, the temperature being 68° F. (20° C.):

Wave-length (Å)	6560 red	5890 yellow	5180 green	5000 blue-green	4480 blue	2790 ultra-violet
Angle	17·25°	21·72°	28·62°	30·78°	39·24°	114·5°

The enormously greater rotation suffered by the ultra-violet rays in comparison with the visual rays and especially the red end of the spectrum will be noticed; quartz, unlike glass, is transparent to the ultra-violet rays.

The rotational property of quartz has an important effect upon the interference-figure yielded by a section, cut at right angles to the prism edge, when viewed between crossed nicols in convergent light. The figure (plate VI, 2) consists of the black cross and, in white light, coloured rings of the normal uniaxial type; but the arms of the cross do not pass within the first ring, and the central area is coloured, the tint depending upon the thickness of the section. If the analysing nicol be rotated alone, the tint of the area will change, and the order of the change will reveal whether the section be right-handed or left-handed; it is the former if the colour passes from blue through purple to red on a right-handed rotation of the analyser, and the latter if a similar effect needs a left-handed rotation.

The application of heat has the usual effect of weakening the colour and, if it be sufficiently prolonged and the temperature sufficiently high, of driving it off altogether. Thus cairngorm or citrine demands little heat, amethyst rather more, and rose-quartz a red heat to lose the colour entirely. With less heat amethyst is altered in colour to a deep orange. Yellow quartz, which owes its colour to the effect of heating, is distinguishable from the naturally coloured stone, citrine, by its lack of dichroism; citrine invariably shows distinct, if slight, dichroism. Following an accidental discovery that some Brazilian amethyst could be changed to a transparent green by heating, the process has since been deliberately applied to produce material marketed in New York under the name of prasiolite (an unfortunate choice, the term praseolite having long been used in mineralogy for an alteration product of cordierite). Irradiation, on the other hand, will restore colour to a colourless quartz, though not necessarily the tint that has been lost.

Another result of the low symmetry of the structure of quartz is that a crystal, if heated, passed quickly through a flame and allowed to cool, will develop pyroelectric charges, which are revealed if it be dusted with a mixture of red lead and sulphur (p. 140). Similar charges are developed by pressure, even by the fingers, or by an electric stress; this property is known as piezoelectricity, from the Greek word πιέζω (press).

The lustre of quartz is commonly vitreous, but occasionally tends to be resinous.

The specific gravity is also remarkably constant, though necessarily more variable than the refractive index, because of the effect produced by cavities or inclusions. For rock-crystal it is constant at 2·651; for citrine, amethyst and rose-quartz it ranges from 2·647 to 2·656, and for aventurine it runs rather higher, from 2·66 to 2·68.

Quartz was assigned by Mohs the symbol 7 on his scale of hardness. It cannot be scratched by a knife, and it resists the abrasive action of ordinary dust. It seldom shows any cleavage.

Except that the fibrous varieties are aways cabochon-cut in order to achieve the cat's-eye effect, quartz is step-cut or brilliant-cut according to the purpose for which the stone is required.

In addition to providing gem material, quartz serves many useful purposes. On account of its superior hardness it is sometimes selected in preference to glass as the material for spectacle lenses, because it is not easily scratched in the ordinary course of wear, and the surface of the lenses therefore retains its polish indefinitely. It further surpasses glass in transparency to the ultra-violet rays, to which photographic films are chiefly most sensitive, and is suitable for lenses employed in delicate photographic work. Spheres of colourless transparent quartz are valued as the crystal-gazer's stock-in-trade.

Quartz has rather unexpectedly turned out to be invaluable for maintaining the wave-length of a broadcast emission, because of its piezoelectric properties. Vibrations can be set up by electric excitation in quartz plates, bars or rings, and the stability of the mechanical oscillation can be made to ensure the stability of the electric oscillation, using the fact that the amplitude of the latter is enormously increased when it harmonizes with the former. The same principle has been adopted in the construction of a timepiece of remarkable accuracy. It is obvious that the pieces of quartz that are used for such purposes must be free from any trace of twinning, because otherwise the piezoelectric axes would be confused and the oscillatory properties interfered with. It has been found by experience that many pieces of quartz, which had appeared simple in crystal development, were in reality twinned and useless therefore as a vibrational regulator.

In the form of sand, quartz finds extensive service as an abrasive, when impregnated in sand-paper, scouring soaps and cleansing pastes, and as an ingredient of glass, cement and bricks.

When fused in the oxyhydrogen flame, quartz passes into silica-glass, which has entirely different physical properties. As in glass generally the refraction is single, and the refractive index is reduced to 1·460, the colour-dispersion being 0·008; the specific gravity also is lower, 2·2, and the hardness is 5 on Mohs's scale. Silica-glass is of great service in the laboratory and for culinary purposes, because it withstands sudden and unequal heating without risk of fracture. It can be drawn out into threads as fine as silk but without silk's tendency to acquire a slight permanent twist, and is therefore invaluable for delicate torsional experiments, as for instance in the determination of the weight of the earth.

One of the treasures of the Museum of Practical Geology in London is the huge vase of aventurine quartz, standing on a base of grey porphyry, which was given by the Emperor Nicolas of Russia to Sir Roderick I. Murchison, Bart., Director of the Geological Survey, and bequeathed by him to the Museum. The mineral came from the Korgon Mountains, Tomsk Province, Siberia.

Quartz is one of the easiest of the gemstones to identify by means of either its optical properties or its specific gravity. The coloured shadow-edges shown in white light in a refractometer of the ordinary type are unmistakable and quite different from those seen in the case of glass of the same refractivity. In specific gravity, too, quartz stands apart from any other gemstone with which it might be confounded.

The colour of amethyst is so characteristic that usually no test is necessary. Citrine is the most likely variety to be confused with other gemstones supplying stones of similar tint; that it has often been mistaken for topaz has been mentioned. Methylene iodide at once separates the two, since topaz sinks in it, whereas quartz easily floats.

Since the acid igneous rocks are defined as those in which there is an excess of silica, quartz is found abundantly in such rocks. It is also the main constituent of the sandstones which have resulted from their disintegration. Further, it is a common constituent of many metamorphic rocks, and geodes and veins are often lined with it in well-formed crystals.

The brilliant, limpid crystals of rock-crystal have come to light in many and widely separated parts of the world. This variety, as has already been explained, was early known among the perpetual snows of the Swiss Alps and there first received the name of crystal. Good crystals have come from Bourg d'Oisans, Isère, France, the marble-quarries at Carrara in northern Italy, and the Marmaros Comitat in Hungary. Small, lustrous crystals have been picked up and have gained for themselves such misleading names as 'Isle of Wight', 'Cornish' or 'Bristol-diamonds'. Similar material has been found in the Tanjore district, Madras, where it is used for cheap jewellery and is called 'Vallum-diamond', and also on the Indus, where it is used for necklaces and is called 'Mari-diamond'. Japan has supplied a quantity of attractive specimens, particularly of the third type of twinning, in which the two individuals are distinct and the directions of their prism edges are very nearly at right angles to one another. Good rock-crystal has emanated from Madagascar and from various places in the United States. An immense quantity of excellent material, which has been used for optical and electrical purposes, has been supplied by Brazil; the transparent pieces have at times, indeed, been so large that they have been fashioned into the spherical balls of crystal-gazers.

Brazil, too, is noted for its splendid amethysts. The principal area providing them is in the State of Rio Grande do Sul and spreads over the border into Uruguay. Good crystals have come from the gem gravels of Ceylon, the Ural Mountains in Russia, and the Echigo, Hoki and Iwaki Provinces of Japan. The mauve crystals found in Keem Bay, island of Achill, off the west coast of Ireland, are known as Achill amethyst. Three splendid cut specimens are on exhibition in the Mineral Gallery of the British Museum (Natural History). The largest, oval in shape, weighs 343 carats and came from Brazil. The remaining two came from Russia; the one is hexagonal in contour and weighs 90 carats, and the other, a deep purple in colour, is circular in form and weighs 75 carats.

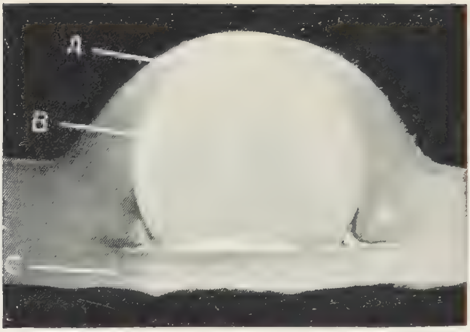
Cairngorm, of excellent quality, was formerly plentiful in the highlands of that name in Scotland, but is now not often found. It is still prized and extensively used in that country for ornamental purposes, especially in connexion with the Highland costume. Splendid examples of citrine have come to light in many of the Brazilian states, especially Minas Gerais, São Paulo and Goyaz, where it is usually confused with topaz. Fine smoky-quartz, which will turn yellow if heated, has occurred at Hinojosa, in the Province of Córdoba, Spain. Fine cairngorm has originated at Pike's Peak, Colorado, U.S.A., and also in Manchuria. Citrine is among the many gemstones supplied by Madagascar.

The delicate rose-quartz is not widely dispersed. It has been obtained in the valley of the Jequitinhonha River, Minas Gerais, Brazil; in the pegmatites of South-West Africa; with citrine and smoky-quartz in Madagascar; at Goto, in Iwaki Province, Japan; at Bodenmais, in Bavaria, Germany; at Paris, in Maine, and near Custer, Black Hills, South Dakota, U.S.A.; and near Sverdlovsk (Ekaterinburg) in the Ural Mountains, Russia.

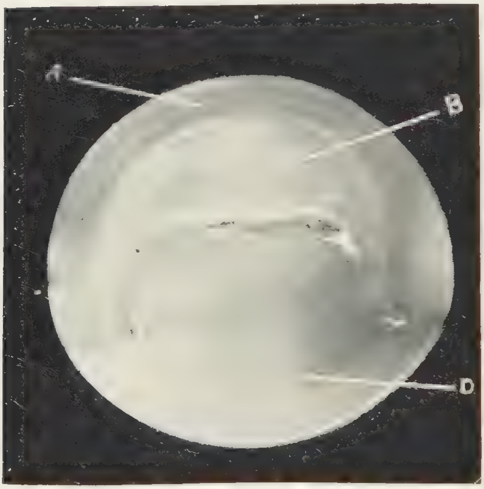
The best quartz cat's-eyes have been found in abundance in the gem gravels of Ceylon; mostly greenish in colour, but sometimes brownish-red and yellow, they are usually confused with the chrysoberyl cat's-eyes which are associated with them. Greenish cat's-eyes, of an inferior quality, have been brought from the Fichtelgebirge, in Bavaria, Germany, and sold as 'Hungarian cat's-eye', although no such stones have come from Hungary; another instance of erroneous names which should be abandoned. The silicified crocidolite which has been designated hawk's-eye and tiger's-eye or tiger-eye has been found in considerable quantity near Griquatown, north of the Orange River, South Africa; when it was a novelty, it commanded high prices. A similar substance, which has retained the original blue colour, has come from near Salzburg, Austria. A locality for reddish-brown aventurine, containing haematite, is Cape de Gata, Spain. Green aventurine, containing fuchsite, is found in India, and is marketed under the misnomer 'Indian-jade'. It is not found as single crystals of quartz but as an aggregate of interlocking crystals, and is in fact a metamorphic rock (quartzite).

A note of caution should be sounded for the benefit of those who, while on holiday by the sea, may pick up a pretty pebble or two and may think how nice it would be to have them cut to wear as ornaments. It is possible to find suitable material, clear and transparent, though possibly water-worn, and either colourless or of an attractive tint, but such material is far from common and is hardly likely to reward a casual search. If the stones be taken to a local lapidary, it has been known to happen that, lest he lose business by explaining that they are not worth cutting, since the result would be disappointing, he accepts the job but substitutes other stones already cut, bought by the gross, or even paste; the customer, on the other hand, receives a pretty bauble and is seldom grateful if he be told that he might have got one like it for a fraction of the price paid.

XXIII. Opal mines, White Cliffs, New South Wales



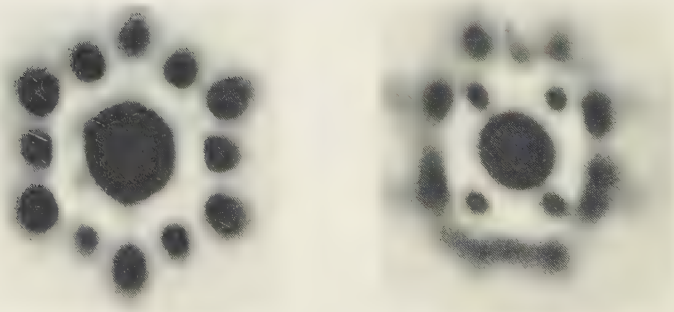
1. In the Oyster



2. When finished

A. *Pearly deposit.* B. *Piece of mother-of-pearl inserted in oyster.* C. *Outer shell of oyster.* D. *Mother-of-pearl back added.*

SECTIONS OF ‘JAPANESE’ PEARL



1. Native pearl 2. Cultured pearl

X-RAY PHOTOGRAPHS OF PEARL

XXXII

OPAL

That opal excited the keenest admiration in early days is evident from Pliny's enthusiastic description of these stones: 'Of all precious stones, it is opal that presents the greatest difficulty of description, it displaying at once the piercing fire of carbunculus, the purple brilliancy of amethystos, and the sea-green of smaragdus, the whole blended together and refulgent with a brightness that is incredible.' [1] From a passage a little further on in his work it appears that the faker even in those days was well acquainted with the possibility of counterfeiting opal by means of glass; Pliny proceeds to give a test for distinguishing the true from the false opal which can hardly have been infallible:

> 'There is no stone that is imitated by fraudulent dealers with more exactness than this, in glass, the only mode of detecting the imposition being by the light of the sun. For when a false opal is held between the finger and thumb, and exposed to the rays of that luminary, it presents but one and the same colour throughout, limited to the body of the stone: whereas the genuine opal offers various refulgent rays in succession, and reflects now one hue and now another, as it sheds its luminous brilliancy upon the fingers.' [2]

Owing to the foolish superstition which flourished during much of last century and still lingers even now, that it is unlucky to wear opals, this gemstone has long lain under a cloud which began slowly to lift only when the black-opal was discovered in Australia. Indeed, the marvellous crimson glow which at a chance movement

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[1] 'Atque in pretiosissimarum gemmarum gloria compositi, maxime inenarrabilem difficultatem dederunt. Est enim in iis carbunculi tenuior ignis, est amethysti fulgens purpura, est smaragdi virens mare, et cuncta pariter incredibili mixtura lucentia.' Loc. cit., book 37, ch. 6.

[2] 'Nullosque magis India similitudine in discreta vitro adulterat. Experimentum in Sole tantum. Falsis enim contra radios libratis, digito ac pollice unus atque idem translucet colos in se consumptus. Veri fulgor subinde variat, et plus huc illucque spargit, et fulgor lucis in digitos funditor.' Ibid.

sweeps over a piece of opal, black with the darkness of night, is not the least striking phenomenon that modern jewellery has to offer.

The two chief varieties into which opal may be divided are white-opal and black-opal. Both terms are used in a wider sense than what would be understood by a strict interpretation of the words. The intrinsic colour of white-opal is always light, but it may be some tint, such as yellowish, other than white. A true black-opal is very rare, and most of this variety is dark grey or blue by reflected light. That the coloration is not due to ordinary absorption is shown by the fact that the transmitted and reflected beam have complementary tints; a blue stone, for instance, is yellow when viewed by light that has passed through it. In many pieces of black-opal the iridescent specks are too tiny to be worth isolating, and the whole iron-stained mass is cut and polished, and is sold as opal-matrix. The name of the species has reached us through the Latin *opalus*, from the Greek word ὀπάλλιος, which itself comes from a Sanskrit word *upala*, meaning precious stone, indicating that opals were first introduced to Europe from India.

Fire-opal is a variety which, as its name indicates, is reddish or orange in tint. It is fairly transparent and possesses only slight milkiness, but viewed in the appropriate directions it displays iridescence. Harlequin-opal has a variegated play of colour on a reddish ground. The term, girasol, also has been used for a fire-opal; it originated from the Latin words *girare* (turn) and *sol* (sun) and intrinsically has the same meaning as heliotrope, which has come from the Greek, but has a different significance. Gold-opal is used to-day as an alternative name for fire-opal. Wood-opal is, as its name implies, wood that has been petrified by opal. Hyalite, sometimes called Muller's glass after its discoverer, is a remarkable opal which is as clear as glass; hence its name from the Greek word ὕαλος (glass). Cacholong is the bluish-white porcelain variety, very porous and adhering to the tongue, which is highly prized in the East; the name is adapted from *kaschtschilon*, a word of Tartar origin. Hydrophane, which is transliterated from the Greek word ὑδροφαινής (apparent in water), is a curious form which has to be soaked in water before its iridescence is developed, the reason being that until water, which in refractivity is not far inferior to opal, penetrates into the cracks much of the light falling upon them is totally reflected at the nearer side and fails to cross them. It is, indeed, surprising how much water these hydrophanes can absorb.

In composition opal is silica, SiO_2, with an amount of water varying from 6 to 10 per cent in precious opal. When pure it is colourless, but is nearly always more or less milky and opaque, or tinted various dull shades by the ferric iron and other impurities present. Opal differs from the rest of the principal gemstones in being not a crystal but a kind of solidified jelly, and it depends for its attractiveness upon its characteristic iridescence, which is in consequence sometimes called opalescence (p. 79). This effect results from the fact that, as the jelly cooled, it no longer remained uniform in texture, but assumed the form of a series of extremely thin films, which differed slightly in refractivity (p. 80). Owing to this slight want of homogeneity these films act on light in the same way as soap-films, and give rise to similar colour phenomena, the thinner and more uniform the cracks the greater being the splendour of the display; exactly what colour is seen depends upon the thickness of the cracks and the direction in which they are viewed. In certain instances the mass is fissured with actual cracks, which contain air and are not filled up with solid material, such opals lack iridescence until the cracks have been filled with water. Some opal is almost water clear (water-opal), but nevertheless displays vivid iridescence when viewed in an appropriate direction. The presence of infra-minute silica crystals has been revealed by X-ray examination. A rough piece of opal is shown in colour on plate XVII.

The refraction in opal is single and the values of the refractive index vary from 1·444 to 1·464. The lustre is sub-vitreous to resinous. The specific gravity ranges from 2·00 to 2·20; for the Australian opal it is about 2·12, and for the material from Mexico it ranges from 1·98 to 2·03. Opal is somewhat soft, varying from $5\frac{1}{2}$ to $6\frac{1}{2}$ on Mohs's scale, and therefore is easily scratched.

Except that the fire-opal variety may be faceted, opal is usually cabochon-cut either in the flat or the steep shape, generally the former in brooches and pendants and the latter in rings. Opals call for cautious handling. Many besides those called hydrophane will absorb some liquid, and their appearance may be spoilt, if they be dipped into dirty water, or ink or other coloured fluids be allowed to drip upon them. Owing to the peculiar nature of their structure opals are very susceptible to the effect of heating, and their appearance may be irretrievably damaged if they be heated.

The price of opal varies greatly, depending upon the intrinsic colour and the uniformity and brilliance of the colour effects.

As was known in Pliny's day, opal may be imitated by heating glass and suddenly cooling it so that it is riddled with cracks. Since the resulting cracks are filled with air and not solid matter the simulation is very indifferent. Opal can always be picked out by its low refractive index.

The oldest mines, which up to modern times were the only extensive deposit of opal known, are near Červenica, Slovakia (formerly in Hungary, for which reason the product was called 'Hungarian-opal'.) The gemstone is found with marcasite, pyrites, stibnite and barytes in an andesite rock, the principal places being Mount Libánka and Mount Simonka. It was from this region probably that all the opals known to the Romans emanated. The pieces have always been mostly small, and large ones are now very rare.

The Hungary mines proved quite unable to compete with the rich fields in New South Wales, Australia, which were first known in 1877. As so often happens, the extensive White Cliffs deposits (plate XXIII) were accidentally discovered. In 1889 a hunter, when tracking a wounded kangaroo, chanced to pick up an attractively coloured opal. Otherwise the wealth of opals might long have lain hidden, so waterless and forbidding is the district. The opal was found in seams in deposits of Cretaceous age, filling cavities in basalt or sandstone, or cracks in wood, or replacing wood, saurian bones and an acicular mineral, which may have been glauberite. In 1905 a still more remarkable field was opened up farther north on both sides of the boundary between Queensland and New South Wales. In it were found opals so relatively dark in colour that they were given the name of black-opal in contradistinction to the lighter-hued stones which alone had previously been known. From Lightning Ridge in New South Wales have come opals so dark in tint as well to deserve the designation of black-opal. The sandstone in which they were found is rich in iron, a fact which is no doubt the explanation of the depth of tint. The Coober Pedy field, rich in white-opal, was discovered in 1915 in South Australia. Here opal is associated with gypsum and alunite in sandstone and claystone of Upper Cretaceous age. Fire-opal has occurred in Western Australia, and opal in Honduras. The 'Devonshire' opal, a magnificent black-opal from Lightning Ridge, with splendid spangled coloration, is the property of the Duke of Devonshire. Oval in contour and shallowly convex in shape, it measures 2 inches (5 cm.) by 1 inch (2·5 cm.), and weighs 100 carats approximately. When Queen Elizabeth II visited Australia in 1954 the South Australian Government presented to Her Majesty a necklace in which was set a 203-carat opal from the Andamooka opal fields.

Mexico has been famed for the magnificent fire-opal it has produced, the principal locality being Zimapán in Hidalgo, but the supply appears to be now exhausted. Other kinds of opal have been found, especially in the State of Querétaro, but they are not so esteemed as the Australian and Hungarian opals. A beautiful opal known as Mexican water-opal also occurs in Mexico.

XXXIII

FELDSPAR FAMILY

The minerals which are grouped together under the family name of feldspar, or felspar, as the word is often misspelt, are second to none in scientific interest, whether because of their crystal forms and varied modes of twinning, or because of the fundamentally important part that they have played in the formation of rocks; but in the realm of jewellery they occupy only lowly rank. Among all the many kinds of mineral which belong to this family, moonstone with its lovely bloom alone is at all commonly used as a jewel. So attractive is its charm that some surprise may be felt that it is not in greater demand. Perhaps it provides an instance where cheapness militates against success in gaining public favour.

The family consists of three principal members: orthoclase and microcline (potash-feldspar), albite (soda-feldspar) and anorthite (lime-feldspar), together with a fourth, celsian (barium-feldspar), which is very rare. Between orthoclase (also microcline) and albite ranges an important series of minerals, alkali-feldspars, and a still more important one between albite and anorthite, plagioclase-feldspars; in addition there is a small series intermediate between orthoclase and celsian.

The name of the family, feldspar, is derived from the German word *feldspat*(*h*) (fieldspar), and was used at first in the translated as well as the semi-translated form, feldspar, but the latter prevailed. The spelling, felspar, which is commonly used in Great Britain, is wrong; it was introduced by R. Kirwan (1733–1812), who was under the mistaken belief that the word was connected with the German *fels* (rock). The correct spelling is used generally by American writers.

Orthoclase and microcline are the same in chemical composition both being a potassium–aluminium silicate, corresponding to the formula $KAlSi_3O_8$, but they differ in their physical properties. Orthoclase belongs to the monoclinic and microcline to the triclinic system, but the angles between the corresponding faces of the crystals are only slightly different; for instance, the angle between the two perfect cleavages, which are parallel to two of the principal faces, is a right angle in the case of orthoclase and 89° 30′ in that of microcline, a difference of only half a degree. Both minerals are commonly twinned, and microcline is so consistently characterized by polysynthetic twinning that the cross-hatching resulting from it is of considerable diagnostic value. Orthoclase is occasionally colourless or yellow; otherwise both minerals are white or shades of grey, except the variety amazonstone or amazonite, which is a bright verdigris-green in colour. Both possess biaxial refraction, in harmony with their crystalline symmetry, and in both the sign of the double refraction is negative. There is, however, a perceptible difference in their refractivity, the values of the least and greatest of the principal refractive indices being 1·518 and 1·526 for orthoclase, and 1·522 and 1·530 for microcline, the maximum amount of double refraction, however, remaining unchanged. It should be noted that the clear yellow orthoclase from Madagascar possesses appreciably higher refractive indices, 1·522 and 1·527, owing to the presence of iron, which in fact is the cause of the colour; its specific gravity is normal in value. The specific gravity is the same for both, namely 2·56. Mohs selected orthoclase as the standard of the symbol 6 on his scale of hardness; microcline may be slightly harder, ranging from 6 to 6½. Both minerals possess two directions of excellent cleavage, which are either at right angles to each other or nearly so, as was described above. Their lustre is vitreous, tending to be pearly on cleavage surfaces. The colour-dispersion of all the feldspars is small, amounting only to 0·012 for the *B–G* interval.

Orthoclase was so named because its cleavage directions are at right angles, from the Greek words *ὀρθός* (right) and *κλάσις* (cleavage). Microcline is the English form of the German word, *mikroklin*, from the Greek words *μικρός* (small) and *κλίνειν* (to incline), the significance being that the cleavage planes are mutually inclined at an angle which differs slightly from a right angle.

The pure or nearly pure orthoclase is known as adularia from the area in Switzerland where these clear, few-faced crystals were first found, and was so named after the Adular Mountains; actually the locality is in the St Gotthard region and not in the mountains now called by that name, but in early days it was applied loosely to the whole of the central Alps, including the St Gotthard. Sanidine is a variety in the form of glassy tabular crystals, and was so named from the Greek word *σανιδ-*, *σανίς* (board).

Amazonstone or amazonite, so called after the Amazon River in South America, is the opaque, verdigris-green variety of microcline.

Albite is the soda feldspar, corresponding to the chemical formula

$NaAlSi_3O_8$, and is an end-member of the important series of minerals called the plagioclase-feldspars. It is triclinic in symmetry, but the angles between its crystal faces are near those of the corresponding faces in the case of orthoclase. As in the case of all the feldspars, the crystals of albite are frequently twinned. It may be colourless, but is commonly various shades of grey in colour. It possesses two directions of easy cleavage, which are mutually inclined at an angle of 86° 24′. The double refraction is biaxial and positive in character, and the values of the least and greatest of the principal refractive indices are 1·525 and 1·536. Its specific gravity is 2·62, and hardness 6 to $6\frac{1}{2}$ on Mohs's scale. The lustre is vitreous, but tending to pearly on the cleavage faces.

Albite owes its name to its usually white appearance, the name coming from the Latin word *albus* (white). The name plagioclase comes from two Greek words *πλάγιος* (oblique) and *κλάσις* (cleavage), in allusion to the distinct divergence from a right angle of the angle between the two cleavage planes.

Anorthite, the other end-member of the plagioclase-feldspars, is the lime-feldspar, corresponding to the chemical formula $CaAl_2Si_2O_8$. It is likewise triclinic in symmetry—a fact which its name is intended to indicate, being derived from two Greek words *ἀν* (not) and *ὀρθός* (upright); the derivation is, however, not very happy, because there exists a Greek word *ἄνορθος*—true, rarely used—in which the first syllable has another significance, and the whole word means upright, the contrary to what was intended. It possesses the customary pair of perfect directions of cleavage, the angle between them being 85° 50′, and the crystals are frequently twinned. Its colour is usually white or colourless. The double refraction is biaxial, and negative in character: the values of the least and greatest of the principal refractive indices are 1·576 and 1·588. Its specific gravity is 2·76, and hardness 6 to $6\frac{1}{2}$ on Mohs's scale. The lustre is the same as for albite.

For convenience, names have been assigned to intermediate parts of the plagioclase series. If we represent the composition of pure albite by the symbol Ab and that of pure anorthite by the symbol An, the following shows the customary usage:

Albite	$Ab_{100}An_0 - Ab_{90}An_{10}$
Oligoclase	$Ab_{90}An_{10} - Ab_{70}An_{30}$
Andesine	$Ab_{70}An_{30} - Ab_{50}An_{50}$
Labradorite	$Ab_{50}An_{50} - Ab_{30}An_{70}$
Bytownite	$Ab_{30}An_{70} - Ab_{10}An_{90}$
Anorthite	$Ab_{10}An_{90} - Ab_0An_{100}$

In the following table certain physical properties corresponding to various points in the series are given, the figures in the brackets being the ratio of the albite to the anorthite molecule and the refractive indices the least and the greatest.

PLAGIOCLASE-FELDSPARS

	Refractive Indices		Sp. Gr.	Cleavage Angle
Albite (1 : 0)	1·525	1·536	2·62	86° 24′
Oligoclase (4 : 1)	1·538	1·547	2·65	86° 32′
Andesine (3 : 2)	1·550	1·557	2·68	86° 14′
Labradorite (2 : 3)	1·558	1·567	2·70	86° 4′
Bytownite (1 : 4)	1·567	1·576	2·73	85° 56′
Anorthite (0 : 1)	1·576	1·588	2·76	85° 50′

The sign of the double refraction, which is positive for albite, changes to negative in the oligoclase stage, back to positive in the andesine stage, and again to negative between labradorite and bytownite.

Oligoclase was so named because it was wrongly thought to have a less easy cleavage than albite, being derived from the Greek words ὀλίγος (small) and κλάσις (cleavage). The remaining names come from places where the corresponding material was first known: Andes in South America, Labrador in North America and Bytown (now Ottawa) in Canada.

Moonstone, which alone of the feldspar varieties holds a secure place in jewellery, owes its lovely sheen to its peculiar structure. It is an intimate combination of orthoclase and albite in an arrangement of thin layers which is known as schillerization,[1] and the thinner they are the deeper the beautiful blue bloom which is so much admired. If the layers be relatively thick, the sheen is merely white and nothing like so attractive. For the phenomenon to be visible the light must be reflected from these layers.

Labradorite, one of the plagioclase-feldspars, is noted for the beautiful play of colours displayed by a cleavage surface, when viewed in the appropriate direction. This iridescence is caused by the lamellar nature of the structure, parallel to the less perfect direction of cleavage, resulting from the effect of repeated twinning. The natural colour of the mineral is rather drab, only greyish shades being shown, but it forms an effective foil for the brilliant green, yellow or red that sweep over it as the piece is moved. Black moonstone is a dark labradorite with a bluish play of colour.

Sunstone is a feldspar which appears to glow with internal yellowish

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[1] The German word *schiller* (iridescence, glitter) has been adopted to signify the type of mineral structure which is manifested by a play of colours.

or reddish beams, due to reflections from crystals of an iron mineral, haematite or göthite, scattered within the structure. It gained its name because of the suggestion of self-luminescence. When the crystals are flakelike, a spangled effect is produced, and the material is called aventurine feldspar.

Hyalophane is a rare barium orthoclase, which owes its name, from two Greek words ὕαλος (glass) and φαίνειν (appear), to the glassy crystals, resembling those of adularia, in which it is found.

Moonstone is invariably cabochon-cut in such a way as to exhibit its characteristic sheen, and labradorite is usually fashioned in flat pieces parallel to the lamellae. Transparent, colourless or yellow, orthoclase is sometimes faceted as a curiosity. Such stones might be mistaken for quartz, because in their refractive indices, double refraction and specific gravity the two species are close together. It is true that quartz is perceptibly harder than orthoclase, but hardness is always a test to be chary of, lest the stone in question be damaged. Careful examination with a refractometer will distinguish them with certainty, because they are of opposite optical sign. Quartz is positive, and therefore the shadow-edge corresponding to the lower refractive index is the one that remains invariable in position, whereas orthoclase is negative, and the stationary shadow-edge corresponds to the higher refractive index; orthoclase is biaxial, but the mean is only 0·002 less than the greatest of the principal refractive indices.

The feldspars *per se* play a comparatively small part in industry, chiefly as a component of glazes or pottery; it is when they have been broken down by weathering to china-clay, soil, etc., that they become of primary importance in ceramics, agriculture, and so on.

The feldspars occur in great abundance in igneous and metamorphic rocks, and form an important basis for the classification of such rocks. Their general distribution throughout the world is very wide, but material which can be of service for ornamental purposes is, on the other hand, comparatively sparse.

Moonstone has been found in abundance in the gem gravels in southern Ceylon and also *in situ* in dykes in the Central and Southern Provinces of the island. The stones mostly display a white sheen, but some are favoured with the coveted blue bloom. During recent years the finest blue moonstone has come from Burma. Moonstone also occurs in Madagascar and in Tanganyika.

As has already been mentioned, the finest specimens of the colourless orthoclase, adularia, originally came to light in the St Gotthard region, Switzerland, but it is not common now. A recent discovery is the golden-yellow orthoclase from Madagascar, the colour of which arises from the ferric oxide which replaces some of the alumina.

Labradorite occurs in immense quantity on the coast of Labrador, where it was known as long ago as 1770, and also comes from north-eastern Quebec in Canada and from Newfoundland. It has been observed in Russia in large masses in the Ukraine, and in more ordinary sizes in the Urals.

An important locality for amazonstone is Crystal Peak, in the Pike's Peak district, Teller County, Colorado, U.S.A., and it has been known, though in not such profusion, in Kashmir, and in the Urals. In spite of its name, none is found in the region of the Amazon River in South America; there has clearly been some confusion of the bluish-green feldspar with some other green mineral, possibly a jade.

The spangled sunstone has come from Modoc County in California, from the Selenga River, one of the feeders of Lake Baikal in Russia, and from Tvedestrand in Norway.

Section B. Other Gem Materials

XXXIV

OTHER GEMSTONES

AMBLYGONITE

Amblygonite is a lithium-aluminium fluo-hydroxy phosphate, $LiAl(F,OH)PO_4$, which crystallizes in the triclinic system. The name is derived from ἀμβλύς, blunt, and γωνία, angle, in allusion to a habit of the crystals. There is one direction of good cleavage. Crystals vary from almost colourless through pale pink, yellow and bluish tinges. The physical properties vary with the proportion of fluorine to hydroxyl. Extreme values for the least principal refractive index may be expected to be 1·572 and 1·606, and for the greatest 1·589 and 1·636, with an increase of the double refraction from 0·017 to 0·030. The optic sign changes over this range from negative to positive and the specific gravity decreases slowly from 3·1 to 3·0. The hardness is 6 on Mohs's scale. For pale yellow crystals of gem quality, of unknown locality, values of refractive indices of 1·61 and 1·64 (double refraction 0·026) and specific gravity 3·01 to 3·03 are recorded. Amblygonite occurs in granite pegmatites with tourmaline and other lithium minerals.

ANDALUSITE

Challenging the green variety of chrysoberyl known as alexandrite in the remarkable contrast of its dichroic tints, though lacking the latter's ability to change its colour in artificial light, andalusite occurs in clear green crystals which can be cut into stones so as to appeal to the connoisseur in gems. It is not often to be met with as a gemstone, and, when it is, it is frequently confused with tourmaline of a similar general tint. The name comes from Andalusia, the region of Spain where it was first found.

Andalusite is in chemical composition an aluminium silicate, corresponding to the formula Al_2SiO_5. If pure it would be colourless, but it is invariably tinted by the impurities present. The clear material used for cutting is an olive-green to brown in colour. It crystallizes in the orthorhombic system, the crystals being usually in the form of a nearly square prism with the basal face. The double refraction is biaxial in character and negative in sign; the acute bisectrix of the angle between the optic axes is parallel to the prism-edge. The values of the least and the greatest of the principal refractive indices range from 1·627 and 1·640 to 1·641 and 1·648, the double refraction decreasing from 0·013 to 0·007. The three principal absorption tints, corresponding to the axis of the optical ellipsoid parallel to the prism-edge and the two axes at right angles to it, are green, red and green respectively. The red tint, which is so sharply contrasted with the green colour of the stone, is scarcely visible through the prism faces, because in this direction the tint in question is at the best only a reddish-green, but it is conspicuous in the direction parallel to the prism-edge. This orientation must be borne in mind when the cutting of a stone is planned. If it be the intention to display the red tint to the fullest extent, the table must be cut at right angles to the prism-edge. Andalusite has a vitreous lustre. Its specific gravity varies from 3·12 to 3·18, and its hardness is 7½ on Mohs's scale, that is just above that of quartz.

Andalusite may easily be mistaken for tourmaline, but can be distinguished from it with certainty if the refractive indices be carefully measured on a refractometer, since andalusite has a sensibly higher refraction and especially a noticeably smaller maximum birefringence, as well as a perceptibly higher specific gravity. Some specimens of bright green strongly pleochroic andalusite, believed to come from Brazil, show a very characteristic absorption with several sharp lines in the green.

Beautiful green to yellow-brown andalusite has been found with topaz at Minas Novas in Minas Gerais, Brazil, and good material has come from the gem gravels of Ceylon.

Chiastolite, macle or cross-stone, is a curious variety of andalusite, which has resulted from the metamorphism of clay, and displays in sections a cruciform or lozenge-shaped pattern, which, if successive sections are cut, is found gradually to alter in shape. Cruciform pieces are occasionally cut for use as amulets. Owing to the great range in the impurities present the hardness of this variety varies from 3 to 7½ on Mohs's scale. Suitable pieces have come from, among other places, Nerchinsk in Transbaikalia district, Siberia. The name chiastolite comes from the Greek word χιαστός (arranged diagonally). Macle comes through the French from the Latin word *macula* (spot or blemish), and was first applied generally to spots in minerals before being restricted to this variety of andalusite; in French it more commonly means a twinned crystal.

APATITE

The most widely distributed of the mineral phosphates, apatite has turned up in crystals—white, yellow, green, blue or violet in colour, which have occasionally been cut with successful results, but unfortunately it is too soft to withstand much wear, and any of its tints may be matched by those of other and harder gemstones. Its name comes from the Greek word *ἀπάτη* (deceit), because of the diverse and deceptive nature of the various forms of its crystals. A yellowish-green variety, first observed near Murcia in south-eastern Spain, has been called, from its colour, asparagus-stone. Moroxite is a name that was originally given to the blue and bluish-green crystals from Arendal, Norway, and was extended to similar material from elsewhere. The name is derived from the Greek word *μόροξος* (a kind of pipeclay), not a very apt selection.

In chemical composition, apatite is a calcium–fluorine phosphate, corresponding to the formula $Ca_4(CaF)(PO_4)_3$, but some chlorine invariably replaces some of the fluorine; indeed, a chlor-apatite, with no fluorine or very little, does occur, but it is rare compared with the abundant fluor-apatite. In a pure state apatite would be colourless, and its crystals are therefore often pale; the colours which it bears, yellow, sea-green, bluish-green, blue, violet, result from the presence of small amounts of mineral tinctorial agents. Apatite crystallizes in the class of the hexagonal system in which there is a plane of symmetry at right angles to the sixfold axis of symmetry but no plane including that axis is one of symmetry. The crystals are usually stumpy, terminated by the basal face (fig. 21 (1), p. 33). In accordance with its crystal symmetry, apatite possesses uniaxial double refraction, the optical sign being negative. The values of the extraordinary and ordinary refractive indices range from 1·632 to 1·642, and from 1·634 to 1·646 respectively, the double refraction ranging from 0·002 to 0·004; the gem material has values at the lower end of the range. The lustre is vitreous, but may incline to resinous. The dichroism is usually feeble, but in certain varieties it is strong; for instance, the blue stones from the Burma ruby mines have twin-colours, blue and yellow, corresponding to the extraordinary and ordinary principal refractive indices. The specific gravity varies from 3·17 to 3·23. Apatite was selected for the standard, 5, of hardness; it is softer than a knife.

When cut, some apatite might be confused with tourmaline, but it can easily be detected by the extremely small double refraction that it possesses, even though the refractivity is not unlike that of tourmaline; the latter even in daylight almost always displays two distinct shadow-edges in a refractometer, possibly after rotation of the stone on the dense glass, whereas in the case of apatite the pair can barely be separated even in monochromatic light.

Extensive phosphate deposits, which have resulted from the accumulation of animal remains and droppings throughout immense periods of time, occur in nearly all parts of the world, and are of enormous importance to agriculture for fertilizing purposes. Only a small proportion has been completely crystallized as apatite, and most of this is opaque, so that material of gem quality is scanty. Opaque crystals are known to have attained to enormous size; thus one found in Ottawa County, Quebec, Canada, weighed about 5 cwt. (250 kg.) and measured 6 feet (2 m.) in girth. Apatite in small amount also occurs in igneous and metamorphic rocks.

Beautiful violet apatite is known from Ehrenfriedersdorf in Saxony, Schlaggenwald (Slavkov) in western Bohemia, and Auburn, Androscoggin County, Maine, U.S.A.; fine blue and bluish-green apatite from the gem gravels of Ceylon and the ruby mines of Mogok, Burma; sea-green apatite from Ajmer in Rajputana and Devada in Madras, India; and yellow apatite from Cerro Mercado, Durango, Mexico.

AXINITE

For those who care for stones a little out of the ordinary the mineral known as axinite from the typical shape of the crystals (fig. 130), the name coming from the Greek word ἀξίνη (axe), may safely be commended. It provides a range of pleasing tints, such as clove-brown, honey-yellow and rarely plum-blue, and the effect is heightened by the strong dichroism.

Axinite is in chemical composition a complex calcium-aluminium borosilicate, corresponding to the formula $HCa_2(Fe,Mg,Mn)Al_2B(SiO_4)_4$. This variation in composition, particularly the presence of iron and manganese as tinctorial agents, is reflected in the range in colour achieved by this gemstone; in addition to the colours already mentioned it is sometimes pearl-grey. Axinite belongs to the triclinic system; it therefore lacks axes or planes of symmetry. The crystals are usually broad and wedge or axe-like in shape. The double refraction is biaxial in character, negative in sign and small in amount. The values of the least and greatest of the principal indices of refraction vary from 1·674 and 1·684 to 1·684 and 1·696 respectively, the amount of maximum birefringence rising slightly, from 0·010 to 0·012. Axinite is highly dichroic, the three principal colours being pale olive-green, violet-blue and cinnamon-brown. The lustre is highly vitreous. The specific gravity varies from 3·27 to 3·29, and the hardness is about the same as that of quartz, that is, 7 on Mohs's scale, or slightly less. Before the blowpipe axinite fuses easily with intumescence.

Axinite has resulted from the intrusion of molten igneous material into previously formed limestones. Excellent crystals have been found at St Cristophe near Bourg d'Oisans, Hautes-Alpes, France, and more recently axinite of a pleasing violet colour has come from Rosebery in Montagu County, Tasmania. Other localities that may be mentioned are the Botallack mine in Cornwall; Hawksburg, near Ottawa in Canada; and Bethlehem in Pennsylvania, Cold Spring in New York and San Diego County in California, U.S.A.

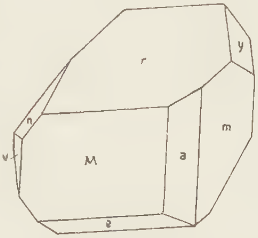

FIG. 130.—A crystal of axinite. The various forms are all pinacoids.

BENITOITE

The discovery of a new mineral, which is at the same time a new gemstone, is a most unusual and in modern times a very nearly unique event; but this is what happened when a sapphire-blue mineral came to light early in 1907. It received the name benitoite from the place where it was found, San Benito County, California, U.S.A. When first found, it was mistaken for sapphire, and many stones were cut and sold as such.

In chemical composition benitoite is a barium–titanium silicate, corresponding to the formula $BaTiSi_3O_9$. The colour, which is probably due to the effect of titanium and is stable, varies from colourless to sapphire-blue and to violet, depending upon the size of the stone. From the crystallographical point of view it is of extreme interest, because it is the sole example among minerals of the class of crystal symmetry which is characterized by a trigonal axis of symmetry and a plane of symmetry at right angles to it. In accordance with its crystal symmetry, benitoite has uniaxial double refraction, the optical sign being positive. The values of the ordinary and extraordinary refractive indices are 1·757 and 1·804 respectively, the birefringence being large in amount, 0·047. The colour-dispersion is large, being 0·039 (B–G) for the ordinary and 0·046 for the extraordinary refractive index; benitoite in this respect therefore vies with diamond. The stones are characterized by strong dichroism, the colours corresponding to the ordinary ray being white, and to the extraordinary ray greenish-blue to indigo, according to the tint of the stone. To secure the best effect therefore it is imperative that in the cutting of the stone the table facet should be arranged so that the direction of the crystallographic axis lies in its plane. The lustre is vitreous. The specific gravity ranges from 3·65 to 3·69, and the hardness is about 6½, that is slightly less than that of quartz.

At a casual glance benitoite may easily pass for sapphire, since they are not unlike in colour and have about the same refractivity. Benitoite has a perceptibly lower specific gravity, 3·67 as compared with 4·00. A characteristic difference is the strong blue fluorescence of benitoite when irradiated by the 'short-wave' ultra-violet lamp (p. 143); sapphire itself is barely responsive to either wave-band of ultra-violet light. A faceted stone may also be distinguished by the refractive indices: the values of the ordinary and extraordinary refractive indices are for benitoite 1·757 and 1·804, and for sapphire 1·773 and 1·765, and therefore not only is there a great difference in the amount of double refraction, 0·047 as compared with 0·008, but also the optical sign is different, and the shadow-edge which remains constant on rotation of the stone on the dense glass of a refractometer corresponds to the lower of the two principal refractive indices in the case of benitoite and to the higher in that of sapphire. Benitoite is much the softer of the two, but a test for hardness is not one to be recommended; it is, however, a point to be borne in mind, because the comparative softness does not fit it for use as a ring-stone. Benitoite also, unlike sapphire, fuses easily before the blowpipe to a transparent glass.

Benitoite was found associated with another rare titanium mineral, neptunite, with the formula $(Na,K)_2(Fe,Mn)Ti(SiO_3)_4$, which was previously known only from Greenland, in narrow veins of natrolite in Diablo range, near the headwaters of the San Benito River, San Benito County, California, U.S.A. Despite careful search it has not been seen except within the original circumscribed area. Several stones, as large as 1½ to 2 carats in weight, were found; the largest of all, a perfectly flawless stone, weighed just over 7 carats and was remarkable in being about three times the next largest in point of weight. It is now in the collection of the United States Museum in Washington, D.C.

BERYLLONITE

As its name implies, the gemstone known as beryllonite is a beryllium mineral, being in chemical composition a beryllium–sodium phosphate, corresponding to the formula $NaBePO_4$. The often complexly faced crystals, which are sometimes twinned, belong to the orthorhombic system. They possess a direction of perfect cleavage parallel to one of the planes of symmetry. The crystals are usually clear, transparent and colourless, but sometimes are faintly tinged yellow. The double refraction, as would be anticipated, is biaxial, the optical sign being negative, and the values of the least and greatest of the principal refractive indices are 1·553 and 1·565. The colour-dispersion (*B*–*G*) is very small, being only 0·010, and the lustre is vitreous. The specific gravity varies from 2·80 to 2·85, and the hardness is rather low, being only 5 on Mohs's scale.

Beryllonite is a rare mineral, and only one locality has supplied it in gem quality: Stoneham, Maine, U.S.A., where it is associated with beryl and phenakite.

BLENDE OR SPHALERITE

Occasionally the mineral known as blende, or sphalerite as it is sometimes called, is found in pieces large and clear enough to warrant their being cut, and owing to its high refraction and large colour-dispersion the results are very pleasing. It is the paucity of really satisfactory material, its lack of hardness and the difficulty in cutting it due to its easy cleavage, that prevent this mineral from securing a firm position as a gemstone. The name blende is the German one for the mineral and comes from *blenden* (deceive), because it is a frequent associate of the mineral galena (lead sulphide, PbS), and was often mistaken for it, but was found to contain no lead; the alternative name, sphalerite, comes from the Greek word σφαλερός (deceitful), and has the same significance.

Blende is simple in chemical composition, being zinc sulphide, corresponding to the formula ZnS, but other elements, particularly iron, cadmium and manganese, are almost invariably present. If it were quite pure, it would be colourless, but it is usually yellowish-brown when transparent, and with a shade deepening to black it becomes almost opaque. It crystallizes in the cubic system, and has a perfect cleavage parallel to the six directions of the regular dodecahedron. Its type of structure is similar to that of diamond. Blende is, of course, singly refractive and its refractive index varies from 2·368 to 2·371. Its colour-dispersion, 0·156 for the *B*–*G* interval, is enormous, being over three times that of diamond. The lustre is adamantine to resinous. Some blende displays the phenomenon of triboluminescence (p. 141) in a most striking manner. The specific gravity ranges from 4·08 to 4·10, and the hardness from $3\frac{1}{2}$ to 4 on Mohs's scale.

Blende can be recognized by its high refraction, which is single in character, and by its softness.

A most important ore of zinc, blende occurs in all parts of the world, often in association with the corresponding lead sulphide, galena (PbS), and in some places the beds that it has formed are of great size. Gem material is comparatively scarce, but has chiefly been found at Picos de Europa, Spain, and Sonora, Mexico. Owing to its high refractive index and single refraction blende, in sufficiently clear and colourless pieces, may with advantage be used to raise the range of a refractometer by replacing the dense glass, which at the best is of much lower refraction.

BRAZILIANITE

A mineral first described in 1945, which has provided material of gem quality, was found in pegmatite in Minas Gerais, Brazil, and from its country of origin has been given the name brazilianite. In chemical composition it is a hydrous sodium-aluminium phosphate with the formula $NaAl_3(OH)_4(PO_4)_2$. It crystallizes in the monoclinic system, and in colour is a slightly greenish-yellow. It is translucent to transparent, and of the principal indices of refraction the least, α, varies from 1·598 to 1·602 and the greatest, γ, from 1·617 to 1·623. The double refraction, positive in sign, varies from 0·019 to 0·021. The specific gravity varies from 2·94 to 3·00, and the hardness is $5\frac{1}{2}$ on Mohs's scale. There is a perfect pinacoidal cleavage. A brilliant-cut stone, weighing 19 carats, is in the American Museum of Natural History, New York, and a still larger stone, weighing 23 carats, has been emerald-cut. Brazilianite has also been found in Grafton County, New Hampshire, U.S.A.

CASSITERITE

The mineral known as cassiterite, or tinstone, is usually opaque, but occasionally provides clear pieces of sufficient size for cutting, the resulting gems being very attractive. The name cassiterite comes through the Latin from the Greek word *κασσίτερος* (tin); to the Roman world Cornwall was known as the Cassiterides.

Cassiterite is simple in chemical composition, being tin oxide, corresponding to the formula SnO_2. For gem purposes it is colourless, yellow or brown in colour, and transparent, but in general it is black or brown, and opaque. It crystallizes in the tetragonal system, and belongs to an important crystallographic group which also includes zircon and rutile. The crystals are usually prismatic in form with pointed pyramidal ends, and are sometimes twinned into knee-shape. In view of its crystal symmetry cassiterite has uniaxial double refraction, the sign being positive, and the values of the ordinary and extraordinary refractive indices are 1·997 and 2·093, the birefringence being large, 0·096, though smaller than that of sphene. The colour-dispersion is large, amounting for the ordinary ray to 0·071 (*B–G*). The lustre is adamantine. The specific gravity of transparent pieces is about 6·7 to 6·8, but rises to 7·1 for opaque masses. On the whole cassiterite is not so hard as quartz, its symbol being 6 to 7 on Mohs's scale, but it is hard enough for ornamental purposes.

Little difficulty should be experienced in identifying a cut stone, if one were to be met with, because its high specific gravity discriminates it from other optically dense gemstones.

Cassiterite is almost the sole source of the metal, tin, and is therefore a most valuable ore in commerce. It has been formed by the action of hot vapours rising from below the earth's crust and is generally associated with quartz, fluor, topaz, tourmaline, apatite and axinite, but in some places, for instance in Malaya, Indonesia and Tasmania, it has been concentrated into placer deposits by the disintegration of the rocks that contained it. Well-known localities for cassiterite are Cornwall, Saxony, Australia, Bolivia, Malaya and Mexico.

CORDIERITE OR IOLITE

This species is distinguished on account of its remarkable dichroism, the principal colours, smoky-blue and yellowish-white, being in such pronounced contrast as to be obvious to the unaided eye. It is almost equally distinguished because of the unusual number of alternative names that is possesses: iolite, which is perhaps more often used than cordierite for gem varieties, dichroite, 'water-sapphire' and 'lynx-sapphire'. At the beginning of the nineteenth century it was unhappily styled 'Spanish-lazulite', but this name has fortunately been discarded. The name cordierite is after Pierre Louis Antoine Cordier (1777–1861); iolite from the Greek word *ἴον* (violet) in allusion to its colour; and dichroite from the Greek word *δίχροος* (two-coloured) in allusion to its remarkable property. The undesirable names 'water-sapphire' and 'lynx-sapphire' have been used in Ceylon for the light-blue and dark-blue stones respectively.

Cordierite is various shades of blue in colour. In chemical composition it is a magnesium (iron)–aluminium silicate, corresponding to the formula $(Mg,Fe)_2Al_4Si_5O_{18}$; the natural mineral often contains hydroxyl. It belongs to the orthorhombic system, the crystals being short and prismatic in habit and sometimes twinned so as to appear hexagonal. There is a moderately good direction of cleavage parallel to a principal face in the prism zone. In accordance with its crystal symmetry, cordierite possesses biaxial double refraction, the optical sign being negative in most specimens, and the values of the least and greatest of the three principal refractive indices range usually from 1·532 to 1·541 and from 1·540 to 1·549 respectively, the amount of double refraction remaining at 0·008, but higher values for the refractive indices have been recorded. The lustre is vitreous. As has already been remarked, cordierite is markedly dichroic, the colours corresponding to the directions of the least, mean and greatest of the principal refractive indices being yellowish, light blue and dark blue. In the direction parallel to the prism-edge the colour appears a deep blue, whereas across the prisms it is yellowish or a pale blue. Some specimens of cordierite from Ceylon present a 'bloodshot' appearance due to abundant inclusions of minute platy crystals of haematite.

The specific gravity is about 2·58 to 2·60, but values as high as 2·66 have been recorded. The hardness is about the same as that of quartz, 7, or occasionally a little harder.

Cordierite is another instance, where a faceted stone must be so disposed that the table facet is at right angles to the prism edge, if the maximum amount of colour is to be revealed. It is, however, worked and polished, if used at all, and not often faceted. A large worked piece, weighing 177 grams, which was formerly in the Hawkins collection, is exhibited in the Mineral Gallery of the British Museum (Natural History).

The finest specimens have been found in the gem gravels of Ceylon. Other localities are Madras, Burma and Madagascar.

DANBURITE

Closely akin to topaz n both crystal form and chemical composition, danburite is overshadowed at all points by its opulent and attractive relative, and presents very slight claim to serious consideration as a gemstone. The best colour that it can provide, a deep-yellow tint, cannot compete with the rich shades of yellow characteristic of topaz, and stones are likely to be cut merely as curios. It received its name from the locality where it was first known, Danbury, in Connecticut, U.S.A.

Danburite is a calcium borosilicate corresponding to the formula $CaB_2(SiO_4)_2$, and appears in orthorhombic crystals, which approach those of topaz in interfacial angles, but unlike the latter have no direction of easy cleavage. Most crystals are almost colourless, occasionally they display pale to deep shades of yellow. In harmony with the crystal symmetry the double refraction is biaxial, the axial plane being parallel to the basal face; in topaz the axial plane is parallel to a face of symmetry in the prism zone. Danburite is interesting, because the angle between the optic axes within the crystal is so near a right angle that the optical sign is negative for red to green light, but changes to positive for the blue end of the visible spectrum. The values of the least and greatest of the principal refractive indices are normally 1·630 and 1·636, but may vary 3 points in the third place of decimals. The colour-dispersion for the *B–G* interval is low, being only 0·016. The lustre is vitreous, but becomes brilliant on polishing. Under the influence of ultra-violet rays it fluoresces a sky-blue tint, much the same as diamond does, and, if heated, it phosphoresces a reddish tint. The specific gravity is almost exactly 3·00, with a possible variation of 0·01, and the hardness is about the same as that of quartz, namely 7 on Mohs's scale. It is fusible before the blowpipe and will colour the oxidizing flame green.

Danburite is an unlucky species. It has two fundamental qualities required in a gemstone; it is fairly hard, and its refractivity is fairly high. No tinctorial agents, however, seem to have been within reach when it formed, and it lacks attractive colours, except possibly a yellow. Danburite is best distinguished from topaz by the specific gravity; for instance in methylene iodide it floats, whereas the latter sinks. Also its double refraction is perceptibly smaller. On the refractometer danburite is very near apatite.

One magnificent stone, which was found at Mogok, is now in the British Museum (Natural History). Step-cut, perfectly transparent, flawless and an attractive wine-yellow shade of colour, it weighs as much as 138·61 carats, and measures 1½ by 1⅛ inches in the girdle section and ⅗ inch in thickness (3·18 by 2·96 by 1·52 cm.). The principal refractive indices are 1·633, 1·636, 1·639 and the specific gravity is 2·998.

In addition to the original locality in Connecticut mentioned above, it has been found in colourless, white or yellow crystals at Mogok, in Upper Burma; in yellow crystals, sometimes of a deep shade, in Madagascar; and in small colourless crystals at Bungo in Japan.

DATOLITE

Datolite is near danburite in chemical composition and supplies gem material of rather similar character, but it is likely to be cut only as a curiosity. It is surpassed in colourless stones by corundum, topaz and even quartz, and the yellowish and greenish shades which are sometimes to be met are far too pale to be attractive; moreover, it possesses little colour-dispersion, and its softness renders it unsuitable for ornamental wear. The name is derived from the Greek word δατεῖσθαι (to divide), in allusion to the granular structure of its massive variety (brown massive datolite is sometimes cut in cabochon form as an ornamental material).

Datolite is a calcium borosilicate corresponding to the formula $Ca(B.OH)SiO_4$, and pure crystals would be colourless; actually most are very nearly so, and their colour is never deeper than a faint tinge of yellow or green. The crystals belong to the monoclinic system, and consequently possess biaxial double refraction, the sign being negative; the plane of the optic axes is parallel to the plane of symmetry. The values of the least and greatest of the principal refractive indices are about 1·625 and 1·669. The refractivity is therefore about the same as that of danburite, but the double refraction, 0·044, is much greater. The colour-dispersion for the *B–G* interval, which is the same as for danburite, is low, being only 0·016. The lustre is vitreous. The specific gravity varies from 2·90 to 3·00, and is therefore slightly less than that of danburite. Its hardness is much lower, being only 5, or slightly more, on Mohs's scale. Datolite fuses readily when heated with a blowpipe, colouring the flame bright green and at the same time swelling up.

Datolite may easily be distinguished from gemstones of similar appearance and refractivity by its relatively large birefringence.

The best gem material has come from Habachtal, near Salzburg, Austria. Other localities for datolite are the Tyrol, the Harz Mountains and New Jersey, Michigan and Massachusetts in the United States. It has also been found near the Lizard in Cornwall.

DIOPSIDE

A member of the pyroxene family of minerals, diopside, alternatively known as malacolite or alalite, has claims for consideration as a gemstone, because of the attractive stones, bottle-green in colour, which it has provided and which are prized at least in the area where they have been found. The name diopside is taken from the French and is derived from the Greek words δις (double) and ὄψις (appearance), in allusion to the effect produced by the double refraction; malacolite comes from μαλακός (soft), meaning that the mineral is softer than the feldspar which is associated with it, and alalite was named from Ala, its original locality.

Diopside, in chemical composition, is mainly a calcium–magnesium silicate, corresponding to the formula $CaMg(SiO_3)_2$, but some iron invariably replaces some of the magnesium, and as the percentage increases the mineral passes into hedenbergite, the formula of which is $CaFe(SiO_3)_2$; the latter name commemorates its original describer, Ludwig Hedenberg. When pure, diopside is colourless, but in nature it is always tinged some shade of green owing to the iron present; sometimes chromium also is present, in which case the colour is a brighter and more beautiful green. With increasing percentage of iron the colour deepens towards black, and the transparency diminishes until what may be called hedenbergite is very dark green, nearly black, and almost opaque.

Diopside belongs to the monoclinic system; the crystals are usually prismatic in form, displaying many faces, and have two directions of easy cleavage, nearly at right angles to one another; there is also a plane of parting parallel to the basal face. Occasionally it is fibrous in character, and, suitably cut, displays a chatoyant effect. In keeping with the crystal symmetry, diopside possesses biaxial double refraction. The plane of the optic axes is parallel to the plane of symmetry, and the acute bisectrix of the angle between the optic axes makes with the prism edge an angle rising from 20° to 36° according to the relative amount of iron present. The values of the least and greatest of the principal refractive indices range from 1·671 and 1·699 to 1·702 and 1·726 for gem material, the double refraction (positive in sign) falling slightly from 0·028 to 0·024, and for hedenbergite rise to 1·732 and 1·751, with double refraction 0·019. Dichroism is noticeable in deep-coloured stones, but is not very marked. The lustre is vitreous. The specific gravity for gem material varies from 3·27 to 3·31, and rises to 3·6 for hedenbergite. The hardness is about 5 to 6 on Mohs's scale.

In colour, diopside is resembled closest by ordinary bottle-glass and by the tektites, but is at once separated from them by its double refraction, which is evident by the apparent doubling of the opposite edges of a faceted stone when viewed through the table-facet. Olivine (peridot) has more of an olive shade of green, and its double refraction is higher, although the general refractivity is not very different.

Beautiful bottle-green diopside has long been known in Ala Valley, Piedmont, Italy; Zillertal, Tyrol; and De Kalb, St Lawrence County, New York, as well as elsewhere in the United States. More recently gem material has come to light in Minas Gerais, Brazil, the gem gravels of Ceylon, in Madagascar and in Burma. A bright-green diopside containing chromium has been found in the blue-ground at Kimberley, South Africa. Fine green chrome-diopside cat's-eyes have come from Burma.

Reference may appropriately be made here to two minerals, allied to diopside, which have been used for ornamental purposes. Diallage is a green lamellar pyroxene with a composition near that of diopside and about the same specific gravity; it is softer, its hardness being only 4 on Mohs's scale. Its name comes through the French from the Greek word διαλλαγή (interchange), and refers to the dissimilar cleavages that it shows. Smaragdite is a diallage that has been more or less completely altered to hornblende. It owes its name to its emerald-green colour.

DIOPTASE

Although dioptase achieves a pretty, emerald-green colour, it seldom yields pieces suitable for cutting; moreover, it is rather soft for use in jewellery, and its excellent cleavage may be troublesome both in cutting and in wear. When it first came to light, dioptase was thought to be emerald. After its true nature was recognized it was given the name dioptase in French from the Greek words διά (through) and ὀπτός (seen), because the incipient cleavage cracks were visible on looking into the crystal. 'Copper-emerald' is an undesirable name for it.

Dioptase in chemical composition is a copper silicate, corresponding to the formula H_2CuSiO_4. The colour is a beautiful emerald-green. It crystallizes in the trigonal system, and the crystals are interesting, because they appear to have the restricted symmetry of the class in which there is a trigonal axis and a centre of symmetry only. The fact that dioptase is often pyroelectric suggests that even this degree of symmetry may arise from repeated twinning. There is an excellent cleavage parallel to the faces of the primary rhombohedron. The values of the ordinary and extraordinary refractive indices range from 1·644 and 1·697 to 1·658 and 1·709, the double refraction, which is uniaxial and positive, at the same time diminishing from 0·053 to 0·051; the colour-dispersion is 0·022 (*B*–*G*). The lustre is vitreous, and the specific gravity varies from 3·27 to 3·35. The hardness is 5 on Mohs's scale, and therefore dioptase can be easily scratched with a steel knife.

Dioptase is not a common mineral and has little industrial importance. Well-crystallized specimens are in greater demand for mineral collections than as possible gem material. Attractive specimens were found in the Kirghiz Steppes in Russia and in many of the gold-washings in Transbaikalia, Siberia and good crystals have come from the Niari River, Congo, and from South-West Africa. Other localities that may be mentioned are Rezbanya in Rumania, Copiapo in Chile and Cordoba in Argentina.

EKANITE. See p. 420.

ENSTATITE

When certain small green stones were found in the blue-ground with diamond in South Africa, they were cut and sold under the pseudonym of green garnet, a doubly heinous offence because they bore no relation whatever to garnet, and a green garnet was known under the name of demantoid; it was perhaps argued that, if a red garnet could be called Cape-ruby, no objection need be raised to calling another stone out of its name. These stones are beautiful in colour, but rarely exceed 2 carats in weight, and consequently seldom enter the market. The name is derived from the Greek word ἐνστάτης (adversary), because of its refractory nature, and hypersthene, the iron-rich member of the family containing enstatite, comes from ὑπερσθένος (very tough), which has a similar significance.

Enstatite is a member of the important family of minerals, known as the pyroxenes, which includes spodumene and jadeite. All the members of the family resemble one another in their crystal form, even though they belong to different systems. Enstatite in chemical composition is a magnesium (iron) silicate, corresponding to the formula $(Mg,Fe)SiO_3$; as the percentage amount of iron increases, it passes into hypersthene. If enstatite were the pure magnesium silicate, it would be devoid of colour, but iron is always present and accounts for the usual green tint, although the rich hue of the South African stones is due partly to the presence of chromium. The crystals belong to the orthorhombic system, and are usually prismatic in form with two directions of easy cleavage parallel to prism faces; there is also a plane of parting parallel to a plane of symmetry in the prism zone. The double refraction is biaxial in character and positive in sign. The values of the least and greatest of the principal refractive indices range from 1·656 and 1·665 upwards as the percentage amount of iron present rises, but for green gem material are 1·665 and 1·674, the maximum amount of double refraction being 0·009. The dichroism is just perceptible by the yellowish tinge of one of the twin-colours, being the more pronounced the deeper the colour of the stone. The lustre is vitreous, but pearly on a cleavage face. The specific gravity may be as low as 3·10, but for the gem material is about 3·26 to 3·28. The hardness is $5\frac{1}{2}$ on Mohs's scale.

Enstatite is easily separated by its refractive indices from other gemstones, such as demantoid, which it resembles in appearance. Kornerupine, which has nearly the same refractivity and specific gravity, differs from it in colour, and has a distinctly larger birefringence.

Enstatite is a constituent of peridotites and serpentines, and is therefore found in blue-ground and even in certain meteorites. It first yielded gem material from the Kimberley diamond mines, but larger pieces, though inferior in colour, have been produced at Mogok in Upper Burma.

The iron-rich hypersthene, into which enstatite passes, is usually too opaque for faceting, but, when spangled with small scales of brookite, it is occasionally cabochon-cut. The values of the least and greatest of the principal refractive indices for hypersthene range from 1·673 and 1·683 to 1·715 and 1·731, and the specific gravity is likewise high, being about 3·4 to 3·5. The dichroism is much more distinct.

Mention should be made of an altered enstatite, leek-green in colour, and close to serpentine in chemical composition, which has occasionally been cabochon-cut. It has a much lower specific gravity, only 2·6, and also lower hardness, 3½ to 4. It was named bastite from Baste in the Harz Mountains in Germany, where it was first discovered. Specimens suitable for cutting have been found in Burma.

EPIDOTE

Often endowed with a peculiar shade of yellowish-green, which is similar to that of the pistachio-nut and is unique among minerals, epidote has occasionally been faceted for the benefit of the few to whom this peculiar tint may appeal. It is the best-known member of a family of minerals, to which its name has therefore been given. They are similar in chemical composition and crystal structure, although as regards the latter the variation is sufficient to assign the crystals to two different systems—the orthorhombic and the monoclinic; the former of them has one member only, zoisite, and the latter includes in addition to epidote itself two others—piedmontite and allanite or orthite. All of them are characterized by the possession of a direction of perfect cleavage, and usually occur in the form of prismatic crystals, richly endowed with faces. The name epidote, from the Greek word ἐπιδοτός (added), was given to it by Haüy, because the base of the prism had one side longer than the other, a reason more ingenious than sound. Zoisite was named after Baron von Zois, piedmontite after the original locality, allanite after Thomas Allan (1777–1833) and orthite from the Greek word ὀρθός (straight), because of its characteristically slender radiating crystals. Pistacite, from the Greek word πιστάκια (pistachio-nut), is an alternative name that has sometimes been used for epidote. Clinozoisite is a variety which has the chemical composition of zoisite but the crystal form of epidote.

Owing to the extensive isomorphous replacement of one element by another, epidote varies very considerably in chemical composition. It is a calcium–aluminium silicate, corresponding to the formula $Ca_2Al_2(AlOH)(SiO_4)_3$. The calcium may in part be replaced by magnesium or iron, and the aluminium by iron, manganese or the cerium and yttrium metals. With increase in manganese, epidote passes into piedmontite (manganiferous epidote) and with addition of the rare metals into allanite. Zoisite contains little iron; there is a rose-pink variety, thulite, which is described elsewhere (p. 461). In colour, epidote is a shade of green, generally pistachio-green or oil-green, but deepens with increasing percentages of iron, and the stones become nearly opaque. Zoisite is much lighter except in thulite. Because of the manganese present in it, piedmontite is a dark shade of red, and allanite is brown to black.

In keeping with the crystal symmetry, all the members of the epidote group have biaxial birefringence, but, whereas in zoisite all three principal optical directions coincide with the crystallographic axes, in the case of the other members two of the former are entirely unrelated to the latter. The optical sign is negative for epidote itself and for allanite, but positive for piedmontite and zoisite. The values of the least and greatest of the principal refractive indices are 1·733 and 1·768 for the clear stones of good colour which are the ones likely to be cut, but with smaller percentages of iron the values may be as low as 1·716 and 1·723. It will be noticed that the maximum amount of double refraction falls from 0·035 to 0·007. The values for piedmontite are high, ranging from 1·738 and 1·778 to 1·750 and 1·832, the double refraction being correspondingly high. For zoisite they are low, namely, 1·696 and 1·702. Epidote is highly dichroic, the principal colours being green, brown and yellow. For piedmontite they are red, violet and yellow. Allanite is too nearly opaque to show the phenomenon plainly. The pink zoisite is strongly dichroic. The colour-dispersion of epidote is 0·030 (*B*–*G*). The lustre is vitreous to metallic, and pearly on the cleavage faces. The specific gravity of epidote is about 3·4 and rises to 3·5 in piedmontite and 4·2 in allanite; it is about 3·3 for zoisite. The hardness is about 6½ on Mohs's scale.

Transparent crystals suitable for cutting have come from Knappenwald, Salzburg, Austria; Traversella, Piedmont, Italy; and Arendal, Nedenäs, Norway. Magnificent groups of rather dark crystals were discovered early this century on Prince of Wales Island, Alaska. Transparent green clinozoisite has come from Kenya; its principal refractive indices are 1·725 and 1·733, and its specific gravity is 3·40.

EUCLASE

The beryllium mineral which was named euclase is so like certain of the paler aquamarines in colour and so difficult to work because of its easy cleavage that cut specimens are seldom seen. Moreover, it is a rare mineral, though not so rare as was formerly supposed; the lovely crystals which it has formed are coveted for mineral collections, and are worth more than the stones which might be cut from them. The name is derived from the Greek word *εὐκλάσις* (good cleavage).

Euclase is a beryllium silicate, corresponding to the chemical formula $Be(AlOH)SiO_4$. If pure it would be colourless and owes its tints, sea-green and blue, to the presence of small proportions of mineral colouring agents. It crystallizes in the monoclinic system, and its crystals are most attractive to the eye, with their elegant prismatic shape and numerous smooth faces (plate XX). There is an unusually easy cleavage parallel to the plane of symmetry, a property which, as has been remarked, renders euclase difficult to cut. In accordance with the crystal symmetry the double refraction is biaxial, the optical sign being positive, and the values of the least and greatest of the principal refractive indices vary from 1·651 and 1·671 to 1·658 and 1·677, the amount of double refraction being about 0·019. The lustre is vitreous, but pearly on the cleavage face. Dichroism is noticeable by variation in the tint. The colour-dispersion is small, being only 0·016 (*B–G*). Euclase may be electrified by friction. The specific gravity is 3·10, and hardness 7½ on Mohs's scale.

Euclase is easily distinguished from beryl, which it resembles in colour, by its refractivity or specific gravity.

Euclase in many shades of blue and green has been yielded by the rich mineral district around Ouro Preto in Minas Gerais, Brazil, and in the Urals, Russia; and has more recently been discovered in Kashmir and in Tanganyika.

FIBROLITE

Gem material has been provided by the mineral which is known as fibrolite, from the fibrous character of the specimens first found, or alternatively sillimanite, after Benjamin Silliman (1779–1864), and as curios a few stones have been cut.

Fibrolite has the same chemical composition as andalusite, the formula being Al_2SiO_5. It is usually densely compact in form, greyish shades of brown and green in colour, and as such has passed for jade. The gem material is a pale sapphire-blue in colour, and so closely resembles the kind of cordierite called 'water-sapphire'. The crystals are prismatic in form without definite terminations; they belong to the orthorhombic system, and possess a direction of excellent cleavage parallel to one of the planes of symmetry. The double refraction is biaxial in character, the plane of the optic axes being parallel to the cleavage face, and the optical sign is positive. The values of the least and greatest of the principal refractive indices are 1·658 and 1·677, the maximum amount of double refraction therefore being 0·019. The colour-dispersion for the *B–G* interval is not large, being only 0·015. The lustre is vitreous. Fibrolite is strongly dichroic, the phenomenon being manifested mainly by fading of tint and not by contrast between the tints. The colours corresponding to the axes of the optical ellipsoid are colourless perpendicular to the cleavage face, sapphire-blue in the direction of the slender crystals or fibres and pale yellow in the direction at right angles to the other two; consequently the crystals appear blue when viewed at right angles to their length, and for the best effect the table facet of a cut stone must contain this direction. The specific gravity is 3·25. The hardness of the crystals is 7½ on Mohs's scale and therefore exceeds that of quartz, but the compact material is appreciably softer than this, ranging from 6 to 7, because of its fibrous character.

No difficulty should ordinarily be experienced in identifying fibrolite should one of the rarely cut specimens turn up, since in its refraction it is well clear of the only gemstones for which it might be mistaken: cordierite and sapphire, the former being as much below as the latter is above it. When pale in colour, however, fibrolite so closely resembles euclase of similar tint that discrimination between them is far from easy. The values of the least and greatest of the principal refractive indices are practically identical in the two cases, and, although the optic axial angle is smaller for fibrolite than for euclase, it is not easily measured with accuracy in a cut stone. Fortunately a determination of the specific gravity will solve the problem, since fibrolite is perceptibly denser, its value being 3·25 as compared with 3·10 for euclase.

Gem material, both as crystals and water-worn pebbles, was first discovered in association with ruby at the ruby mines, Mogok, Upper Burma. Similar material, but corroded, had long been seen in the gem gravels of Ceylon, but was confused with cordierite or sapphire. Some of it, pale greyish-green in colour, contains fibres in parallel arrangement, and yields a cat's-eye effect much like the cymophane variety of chrysoberyl. Water-worn pebbles of massive fibrous fibrolite have been collected in the Clearwater River Valley, Idaho.

HAMBERGITE

A rare beryllium mineral, which was named hambergite after Axel Hamberg (1863–1933), was known to occur only at the original locality in southern Norway, where the crystals are wholly unsuitable for cutting, until it was discovered in Madagascar in large colourless crystals, which lend themselves to gem purposes.

Hambergite is unusual in chemical composition, being a beryllium borate, corresponding to the formula $Be_2(OH)BO_3$. It belongs to the orthorhombic system, the crystals being prismatic in form with an excellent cleavage parallel to one of the principal faces in the prism zone; they are colourless or grey. The double refraction is biaxial, the optical sign being positive, and the values of the least and greatest of the principal indices of refraction range from 1·553 to 1·559 and from 1·625 to 1·631 respectively, the amount of birefringence, 0·072, being larger than for any gemstone except sphene and cassiterite. The colour-dispersion (*B–G*) is small, 0·017 for the greatest principal refractive index, and no fire can be expected from a faceted stone. The lustre is vitreous. In specific gravity hambergite is lower than any other gemstone with the single exception of opal, the value being 2·35. It is, moreover, perceptibly lower than might be expected from its refractivity, 1·592; for instance, in the case of beryl the refractivity is nearly the same, 1·580, whereas the specific gravity is 2·70. Hambergite is slightly harder than quartz, its symbol being 7½ on Mohs's scale.

The considerable double refraction possessed by hambergite easily distinguishes it from the other gemstones—scapolite, beryllonite and beryl—with not very different refractive indices. Since hambergite, when cut, very closely resembles rock-crystal, it has no particular merits as a gemstone beyond its rarity. The only locality for gem material is in central Madagascar.

IDOCRASE

Idocrase, alternatively known as vesuvianite, and in a compact form as californite, has occasionally been found in clear pieces, olive-green or yellowish-brown in colour, which have been deemed worth faceting, and in green compact masses, which have passed for a jade. The name idocrase is taken from the French and was originally derived from the Greek words εἶδος (form) and κρᾶσις (mixing), because in its crystal form it resembled other minerals. The other two names have been taken from localities; the mineral was first discovered on Vesuvius, and jade-like material is known in California. Xanthite, from the Greek word ξανθός (yellow), is the name that was given to the yellowish-brown idocrase from near Amity in New York, U.S.A., and cyprine, from the Latin word *cyprius* (Cyprian), Cyprus being the ancient source of copper, is the pale sky-blue or greenish-blue variety containing copper from Telemark, Norway.

The chemical composition of idocrase is a complex calcium-aluminium silicate, corresponding approximately to the formula $Ca_6Al(AlOH)(SiO_4)_5$. As usual, calcium is replaced by magnesium or iron, aluminium by iron, and hydroxyl by fluorine; some idocrase contains beryllium and some boron. In colour, idocrase is usually some shade of yellowish-brown or green. It crystallizes in the tetragonal system, the crystals being prismatic in shape with usually tapered ends. The optical properties are of unusual interest because of the remarkably small amount of double refraction displayed. It may be as little as 0·001 and rarely exceeds 0·010; moreover, its sign changes from negative for low values of the refractive indices, extraordinary 1·700 and ordinary 1·712, to positive for high values, ordinary 1·716 and extraordinary 1·721. The character of the double refraction normally is uniaxial, as it should be in accordance with the crystal symmetry, but occasionally at the upper limit of the range abnormal biaxial birefringence is shown. The dichroism is not strong, but may sometimes be detected by distinct fading of the tint. The colour-dispersion of the ordinary ray is 0·019 (B–G). The lustre is vitreous. The specific gravity varies from 3·35 to 3·45, and the hardness is about 6½ on Mohs's scale.

A leaf-green or a yellowish-brown idocrase, when cut, may easily be mistaken for a diopside or an epidote respectively, but can at once be distinguished by its optical properties. In refractivity diopside is perceptibly lower and epidote perceptibly higher than idocrase, and, above all, their considerable double refraction discriminates them.

Bright green and brown crystals have come from the Ala Valley in Piedmont and Mount Vesuvius, Italy, Zermatt in Switzerland, Zillertal and Pfitschtal in the Tyrol, and near Lake Baikal, Siberia. Transparent golden-brown crystals occur in the Laurentian Mountains in eastern Canada. The compact variety, californite, which with its green colour or white colour with green streaks closely resembles a jade, has been found in large masses in Sikiyon County and Fresno County, California. Similar material in rolled masses was known much earlier in Switzerland, and was at first thought to be jadeite.

KORNERUPINE

The possibility that the mineral, which was first discovered in Greenland and was named kornerupine after Kornerup, should ever supply material of service in jewellery was undreamt of until it unexpectedly turned up in Madagascar in a guise unknown elsewhere. Apart from the fact that the amount of material available is limited, it is hardly likely to be cut except to meet the taste of those who covet the unusual.

Kornerupine is a complex magnesium–aluminium silicate, corresponding approximately to the formula $MgAl_2SiO_6$, in which some of the aluminium is replaced by iron and, to a smaller extent, boron. When pure it is colourless, but it is usually coloured shades of yellow and brown, and from Madagascar it is sea-green in tint. Kornerupine crystallizes in the orthorhombic system and is usually fibrous or columnar in character; it possesses two directions of perfect cleavage parallel to the faces of a prism form. It is doubly refractive, biaxial and negative in sign, and the values of the least and greatest of the principal refractive indices vary between 1·661 and 1·682 and between 1·674 and 1·699 respectively. The intermediate principal index lies close to the greatest in value, corresponding to a small negative optic axial angle, 3° to 48°. The double refraction varies from 0·013 to 0·017. The colour-dispersion amounts to 0·019 (*B*–*G*). The dichroism is very noticeable, the crystals appearing green when viewed parallel to their length and yellow to reddish-brown across; if therefore this property is to be brought out in a faceted stone, the table facet must be cut parallel to the length. The lustre is vitreous. The specific gravity ranges usually from 3·28 to 3·44, though some lower values are on record, and the hardness is 6½ on Mohs's scale.

Kornerupine is unlikely to be confused with any other gemstone, because it is different in colour and dichroism from others, such as enstatite, euclase or peridot, with similar refractivity and specific gravity.

Clear green crystals have been found in a pegmatite in south Madagascar and in the gem gravels of Ceylon and of the Mogok district, Burma. Specimens have also been observed in Saxony, as well as Greenland, the original locality.

KYANITE

Choice blue examples of the mineral known as kyanite or cyanite, and alternatively as disthene, are sometimes faceted, especially in India, and are apt to be confused with both sapphire and aquamarine. As a mineral it is of interest on account of the extraordinary variation in hardness according to the direction that its crystals display. The name, kyanite or cyanite, is derived from the Greek word *κυανός* (blue); disthene comes from *δίς* (double) and *σθένος* (strength), and alludes to the unequal hardness in two different directions.

Kyanite, like fibrolite, has the same composition as andalusite, namely Al_2SiO_5. It is blue in colour to almost colourless, the colour often being confined to the centre of the blade-like crystals. It crystallizes in the triclinic system, the crystals having commonly the form of long flattened prisms, hexagonal in section, with a basal face. There is a direction of excellent cleavage parallel to the usually large prism face and another less good parallel to a prism face inclined to it at an angle of 74°. In keeping with the lack of symmetry in the crystals, the optical characters are not specially related to the crystal form. The double refraction is biaxial in character and negative in sign; the plane of the optic axes is nearly at right angles to the direction of perfect cleavage, and makes a trace on it which is inclined at nearly 30° to the prism-edge. The values of the least and greatest of the principal refractive indices are about 1·712 and 1·728 respectively. Kyanite displays marked dichroism, the three principal colours being colourless, violet-blue and cobalt-blue. The lustre is vitreous but pearly on the cleavage faces. The colour-dispersion is small, being only 0·020 (B–G). The specific gravity varies from 3·65 to 3·69, the stones of deeper colour having the higher values. The crystal blades are grained almost like wood in that in the direction of their length the hardness is about 4 to 5 on Mohs's scale, but 6 to 7 across; in other words, they can be scratched by a steel knife with the grain but not otherwise. In this remarkable variation, kyanite is unique among minerals.

Whatever resemblance in appearance kyanite may have to sapphire or aquamarine, it can at once be distinguished by its refractive indices or alternatively by its specific gravity.

Kyanite of gem quality has been found with sapphire in Kashmir, and also in Patiala and the Punjab, in India. It also occurs in Burma. Good crystals are known from Switzerland and from the United States, especially Montana. Other localities for kyanite are in Kenya.

PAINITE

A singly terminated transparent deep-garnet-red crystal, weighing 1·7 grams, discovered in a gem gravel from Mogok, Burma, has proved to be a mineral new to science.[1] It has been named after Mr A. C. D. Pain, who first recognized its unusual nature. The precise chemical composition is still uncertain. The crystal is uniaxial, $\omega = 1{\cdot}816$, $\epsilon = 1{\cdot}787$; pleochroism ranges from ruby red for vibrations parallel to the optic axis to pale brownish-orange for vibrations at right-angles. The specific gravity is 4·01, hardness about 8. It is chemically highly resistant. These attributes clearly make painite a potentially useful gem.

PHENAKITE

Phenakite (or phenacite) is a beryllium mineral which owes its name to the ease with which it may be mistaken for quartz, the derivation being from the Greek word φέναξ (cheat).

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[1] G. F. Claringbull, M. H. Hey and C. J. Payne, *Mineralogical Magazine*, 1957, vol. XXXI, pp. 420–5.

It belongs to the class of the trigonal system in which there is an axis of threefold symmetry and a centre of symmetry. There is no pronounced cleavage. The crystals commonly display many smooth faces, and sometimes are interpenetratingly twinned. They are usually clear and colourless, and sometimes slightly yellowish. In chemical composition, phenakite is a beryllium silicate, corresponding to the formula Be_2SiO_4. In keeping with the crystal symmetry the double refraction is uniaxial, the optical sign being positive, the values of the ordinary and extraordinary refractive indices being 1·654 and 1·670 respectively. The double refraction, 0·016, is nearly double that of quartz, and the colour-dispersion (*B–G*), 0·015, is slightly higher. The lustre is vitreous. The specific gravity ranges from 2·95 to 2·97. In hardness, phenakite approaches topaz, being $7\frac{1}{2}$ to 8 on Mohs's scale.

Colourless phenakite is more suitable for cutting than similar quartz, being harder and more highly refractive; nevertheless, on account of the almost entire absence of fire it is in little demand. A determination of the refractive indices at once differentiates phenakite from quartz, and thanks to the refractometer its days of deception are past.

Phenakite of excellent quality has long been known to occur with chrysoberyl at the emerald mines east of Sverdlovsk (Ekaterinburg) in the Ural Mountains, Russia. Crystals, which occasionally were pale red in hue, have been found at several localities in the district of São Miguel do Piracicaba, Minas Gerais, Brazil. More recently phenakite in clear crystals has been produced from Kiswaiti Mountains, east of Mpwapwa, Tanganyika.

POLLUCITE

Somewhat similar pieces to those of hambergite are yielded by another uncommon mineral, pollucite, at its locality in Maine, U.S.A. Owing to their lack of fire they are of little interest, and are cut only as curios. Its name was originally pollux, taken from the ancient mythology, because it occurred with a rare lithium mineral to which the name castor has been assigned; subsequently it was changed to its present form with the usual termination of a mineral name.

Pollucite in chemical composition is a caesium-aluminium silicate, corresponding to the formula $H_2Cs_4Al_4(SiO_3)_9$. It crystallizes in the cubic system, and is occasionally found in the form of cubes; in tint it is colourless or faintly grey. The refractive index is about 1·517 for specimens from Elba and 1·525 for those from Maine; the colour-dispersion is low, being only 0·012 for the *B–G* interval, and the lustre is vitreous. The specific gravity ranges from 2·90 to 2·94, and the hardness is 6½ on Mohs's scale. Pollucite is easily distinguished by its refractive index and single refraction from quartz, and by its low colour-dispersion from glass.

The original locality for pollucite is Elba, but the gem material has come from Maine, U.S.A.

PREHNITE

Named after Colonel von Prehn, who first discovered this mineral, prehnite has been found in nodules of various shades of green in colour, and occasionally the oil-green kind have been cut. The material from South Africa has been wrongly called 'Cape-emerald'.

In chemical composition, prehnite is a hydrated calcium–aluminium silicate, corresponding to the formula $H_2Ca_2Al_2(SiO_4)_3$. It is easily fusible, with intumescence (swelling) before the blowpipe, and is a close ally of the family of minerals called zeolites, from the Greek words ζεῖν (boil) and λίθος (stone), but demands a much higher temperature than they do before it gives up its water. It crystallizes in the orthorhombic system, but distinct crystals are not common. The double refraction is biaxial in character and positive in sign, and the values of the least and greatest of the principal refractive indices are 1·615 and 1·645, the maximum amount of double refraction being therefore 0·030. Owing, however, to the irregular crystallization of the nodular masses, it is likely that instead of distinct shadow-edges an ill-defined nebulous shadow, fading away at about 1·63, will be visible in the refractometer. The lustre is vitreous. The specific gravity varies from 2·80 to 2·95, and the hardness is 6 on Mohs's scale.

Prehnite is widely distributed in eruptive rocks in various parts of the world, but is seldom of use for ornamental purposes. Good material has come from Bourg d'Oisans in Hautes-Alpes, France, Cape Colony in South Africa, Connecticut, and other parts of the United States, Prospect, near Sydney, New South Wales, Renfrew in Scotland and from China. (BOYLESTON Q

RHODIZITE

Originally found in rose-coloured masses in the Urals, the rare mineral, rhodizite, has turned up in yellowish and greenish crystals in Madagascar, and may occasionally be cut as a curio. It derives its name from the Greek word ῥοδίζειν (to be like the rose), in allusion to the fact that, when strongly heated with the blowpipe, it will finally impart a red colour to the flame.

In chemical composition, rhodizite is a potassium (caesium, rubidium)

—aluminium borate, corresponding to the formula $KAl_2B_3O_8$. It crystallizes in the cubic system, but the crystals lack the complete symmetry of the system and display pyroelectricity. The refractive index is 1·69, specific gravity 3·40 and hardness 8 on Mohs's scale; it may be noted that only three gemstones are harder than rhodizite. The lustre is vitreous, inclined to adamantine. Rhodizite may easily be recognized by its refractive index.

The localities are the neighbourhood of Sverdlovsk (Ekaterinburg) in the Urals and Madagascar.

RUTILE, ANATASE, BROOKITE

The native titanium oxide, corresponding to the formula TiO_2, has the unusual property of appearing in three different crystal modifications, corresponding to three distinct crystal structures, all stable at ordinary temperatures, known as rutile, anatase (or octahedrite), and brookite respectively. They occasionally occur in pieces clear and large enough for cutting purposes, but none of them is likely to be cut except as a curio. The name, rutile, comes from the Latin word *rutilus* (red), and refers to the tint sometimes displayed. Anatase was taken from the Greek word ἀνάτασις (extension), and meant that the length of its bipyramid exceeded that of others in the tetragonal system; it was alternatively called octahedrite, because an eight-faced tetragonal bipyramid is a common form. Brookite was named after Henry James Brooke (1771–1857). The element, titanium, was first discovered in rutile.

Both rutile and anatase crystallize in the tetragonal system, but differ in axial ratio and usual habit. Rutile in its crystals resembles cassiterite; they are often prismatic and pointed, and sometimes geniculated as the result of twinning. Brookite crystallizes in the orthorhombic system. All three are adamantine to metallic in their lustre. In colour rutile is reddish-brown to red and occasionally yellowish, anatase is brown darkening to black when opaque, and brookite is yellowish also darkening to black when opaque.

Rutile has uniaxial birefringence, the optical sign being positive, and the values of the ordinary and extraordinary refractive indices are 2·616 and 2·903, the double refraction being colossal, 0·287. The specific gravity varies from 4·18 to 4·25, and the hardness from 6 to 6½ on Mohs's scale. Closely similar values have been obtained on the nearly colourless synthetic gems (p. 206), of which the specific gravity is 4·23.

Anatase also has uniaxial birefringence, but the optical sign is negative. The values of the refractive indices are lower than for rutile, the extraordinary and ordinary being 2·493 and 2·554 respectively, and the double refraction is much less, 0·061. The specific gravity is likewise lower, ranging from 3·82 to 3·95, and so is the hardness, being 5½ to 6 on Mohs's scale.

Brookite is noted for the peculiarity of its optical properties. Its birefringence is normally biaxial, but the axial angle within the crystals, which is 55° for the red lithium flame, diminishes to 30° for the yellow sodium flame, becomes 0° for yellow-green light, the birefringence at this point therefore being uniaxial, and opens out in the plane at right angles to 34° for the green thallium flame. The values of the least and greatest of the principal refractive indices are 2·583 and 2·741, the double refraction, which is positive, being 0·158; in its refractive properties brookite lies between the other two species. The specific gravity varies from 3·87 to 4·01, and the hardness from 5½ to 6 on Mohs's scale.

Of the three species rutile is by far the most plentiful and most widely distributed, and anatase is on the whole commoner than brookite, certainly as regards gem material. A cut synthetic rutile can be identified on sight by reason of the enormous dispersion and double refraction.

SCAPOLITE

The family of minerals, which have been grouped together under the general name of scapolite, first made a bid for recognition as gemstones when about 1913 pink stones were discovered in Burma, and advanced still stronger claims when further discoveries were made first about 1920 in Madagascar and ten years later in Brazil.

In chemical composition the scapolites are sodium–calcium–aluminium silicates with usually some chlorine, and like the garnets and the feldspars may be explained as an isomorphous mixture in varying proportions of two end-members: marialite, with the formula $Na_4Cl(Al_3Si_9O_{24})$ and meionite, with the formula $Ca_6(SO_4,CO_3)(Al_6Si_6O_{24})$, the crystal symmetry being invariably tetragonal. The resemblance to the feldspars can be more readily seen when the formulae are expressed in the form 3 (albite) NaCl and 3 (anorthite) $CaCO_3$. When the scapolites were first discovered and described, their relationship was not at first recognized, and consequently many names were proposed for what were thought to be different mineral species. It is now customary to use scapolite to cover the whole family and apply the better established of the other names that were proposed to the end and intermediate members. Of the names mentioned, scapolite comes from the Greek word *σκάπος* (rod), and refers to the normal shape of the crystals; meionite from *μείον* (less), because the pyramidal faces are less acute than they are in the crystals of idocrase, with which it was first found; and marialite after Maria (Mary) because the original material was immaculately white.

Scapolite belongs to the tetragonal system, the crystals being prismatic in shape and possessing two directions of easy cleavage parallel to the principal faces in the prism zone. It would be colourless, if pure, and the colours of the gem material are due to traces of tinctorial agents. The stones from Madagascar and Brazil have shades of yellow, varying from pale to, in the latter instance, deep gold; those from Burma have a series of tints—white, pink, yellow and violet-blue, of which all except the yellow provide cat's-eyes. The double refraction is uniaxial, and the optical sign is negative; it is of interest to note that the double refraction, which is highest for a scapolite which is rich in the meionite molecule, falls so rapidly to an observed minimum that a pure marialite is probably positive. The values of the extraordinary and ordinary refractive indices are 1·545 and 1·555 respectively for a scapolite rich in the marialite molecule, and rise steadily as the composition changes to 1·555 and 1·577 for one in which the meionite molecule predominates. Scapolite, especially the violet-blue type, is strongly dichroic. The colour-dispersion for the *B–G* interval is low, 0·017. Under the influence of ultra-violet rays, scapolite fluoresces a pale-yellow tint. The lustre is strongly vitreous. The value of the specific gravity rises from a minimum of 2·57 to a maximum of 2·74. The hardness is about 6 on Mohs's scale; but may be as low as 5 owing to alteration. The values of the refractive indices and the specific gravity are as follows for gem material of different tints: pale yellow 1·549, 1·570, 2·68; deep yellow 1·552, 1·574, 2·70; pale pink 1·549, 1·570, 2·67; violet-blue 1·544, 1·560, 2·63.

Pink scapolite may be confused with pink beryl, and the golden-yellow stones resemble beryl and chrysoberyl of similar tint. A measurement of the refractive indices will remove any doubt, since scapolite has sensibly lower refractivity, and, where it approaches beryl in this respect, its birefringence is much higher.

Gem material, in the form of crystals and water-worn pebbles, have been found associated with ruby in the ruby mines at Mogok, Upper Burma. The pink stones from their sheen were called 'pink moonstone'. White, yellow and violet-blue stones have also been seen there. Large, yellow pieces, of varying depth of tint, were discovered with beryl of very similar appearance in Madagascar and also in the State of Espirito Santo, Brazil.

SINHALITE

This recently-discovered mineral has been described, in view of its close resemblance to olivine, on p. 351.

SPHENE

With its high refraction, its marvellous colour-dispersion, and in the deeper-coloured stones its marked dichroism, sphene or titanite as it is alternatively called, might well hope to attain to high rank in the hierarchy of gemstones in spite of its comparative softness were material suitable for jewellery available in sufficient quantity to enable it to be widely known. The name, sphene, is derived from the Greek word *σφήν* (wedge), and was suggested by the shape of the natural crystals. Titanite, the alternative name, was given to it, because it contained the element, titanium, which had then been recently discovered in the mineral rutile; titanium was taken from *τιτᾶνες* (Titans) in the Greek mythology. The original sphene was the yellow material, and the term has been applied more generally to stones light in colour; the original titanite, on the other hand, was dark, brown to black, and the term has continued to be used in that sense, though not definitely restricted to it.

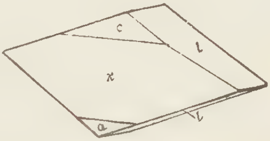

FIG. 131.—A crystal of sphene.

Sphene is a calcium–titanium silicate corresponding to the formula $CaTiSiO_5$, and is therefore akin to a much younger gemstone, benitoite (p. 391). When sufficiently large and transparent for service in jewellery, it is yellow, greenish or brown in colour; it is black or deep-brown when opaque. It crystallizes in the monoclinic system (fig. 131), and possesses a fairly good cleavage in two directions parallel to prism faces as well as a parting due to repeated twinning. The double refraction is biaxial in character, the plane of the optic axes being parallel to the plane of symmetry, and the optical sign is positive. The values of the least and greatest of the principal refractive indices are too high for measurement on the ordinary refractometer; they range from 1·885 and 1·990 to 1·915 and 2·050, the birefringence varying from 0·105 to 0·135; it will be noticed that as regards the latter character sphene enormously excels most other gemstones. Its colour-dispersion, too, is unusually large, amounting to 0·051 for the *B–G* interval, and in this respect it surpasses diamond and is excelled only by demantoid, cassiterite and blende; synthetic rutile leads them all, and is sufficiently clear and light in colour to display this property to advantage. The dichroism is marked in stones of deeper colour, the tints corresponding to the principal refractive indices being nearly colourless, greenish-yellow (in the direction of the axis of symmetry), and reddish-yellow; it might therefore be necessary in cutting a dark stone to arrange that the table facet is at right angles to a direction in which one of the twin tints was nearly colourless. Owing to the high refraction, the lustre is brilliant. The specific gravity for gem material ranges from 3·52 to 3·54. In hardness, sphene is as hard as apatite or a little harder; that is, its symbol is 5 to 5½ on Mohs's scale. It can therefore be scratched by a steel knife, but nevertheless with reasonable care it should give good service as a pendant jewel or in ear-rings.

Sphene may be recognized almost at a glance by the peculiar shade of yellow or brown that it affects, coupled with its extraordinary fire. Confirmatory evidence would be provided by the apparent doubling of at least some of the edges of a faceted stone when viewed through the table facet, a negative test with a refractometer or a determination of the specific gravity.

Sphene suitable for cutting has been discovered in the Tyrol and the Salzburg division of Austria, the St Gotthard district of Switzerland, in Pennsylvania and Maine, U.S.A., and in Canada.

SPODUMENE

Spodumene is a mineral that was scarcely known as a gemstone previous to the discovery of the lovely bluish-pink stones, to which the name kunzite was given. The delightful emerald-green variety, hiddenite, had long been known to mineralogists, but, while the only source of supply was confined to one small pocket, which soon became exhausted, it could hardly expect to aspire to recognition as a gemstone.

The name of the mineral species is the English form of the French name for it, *spoduméne*, which is derived from the Greek word σποδούμενος (burnt to ashes), and alludes to the appearance of the mineral when it was first known; in jewellery it is kept for the yellow stones. Hiddenite was so named after its discoverer, William Earl Hidden (1853–1918); and kunzite received its name after the well-known gemmologist, George Frederick Kunz (1856–1932). Cut specimens of yellowish-green spodumene, hiddenite and kunzite are shown in natural colour on plate XX.

In chemical composition, spodumene is a lithium–aluminium silicate corresponding to the formula $LiAl(SiO_3)_2$, and is interesting because of containing the uncommon element lithium; in its composition it is akin to jadeite (p. 433). It belongs to the monoclinic system, the crystals being prismatic in shape (fig. 132). The prism zone includes the pinacoid parallel to the plane of symmetry and the two directions of perfect cleavage, and the prism faces are often striated and furrowed. The colour is normally nearly white, yellowish or greenish; occasionally it is bluish-pink (kunzite), or emerald-green to pale yellow-green (hiddenite). The double refraction is biaxial in character and positive in sign. The values of the least and greatest of the principal refractive indices differ considerably for the different varieties: for ordinary spodumene they are respectively 1·654 and 1·669, rising to 1·664 and 1·679 with increase in colour; for kunzite 1·660 and 1·675; and for hiddenite 1·662 and 1·676. The birefringence remains about the same, namely, 0·015. The lustre is vitreous, but pearly on the cleavage surfaces. The colour-dispersion (*B–G*) is not large, 0·017. The specific gravity is usually about 3·17 to 3·19, but may reach 3·23. The hardness is 7 on Mohs's scale or a little lower.

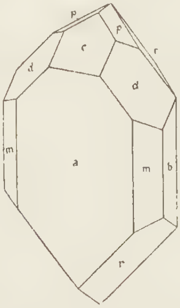

FIG. 132.—A crystal of spodumene.

A notable feature of spodumene is its marked dichroism, the tints, corresponding to the least, mean and greatest of the principal refractive indices being for kunzite violet, amethyst, colourless; and for hiddenite bluish-green, emerald-green, yellowish-green. The direction corresponding to the mean principal refractive index coincides with the axis of symmetry, while that corresponding to the greatest is inclined at an angle of about 25° to the prism-edge and nearly perpendicular to the principal face outside the prism-zone. It follows that in the direction of the prism-edge the tint seen is the combination of the two strong colours, whereas in directions at right angles, that is through the prism faces, either strong colour is diluted by the weak one. In fact, few minerals display the phenomenon of dichroism so beautifully as does kunzite; seen through any pair of prism faces it appears quite uninteresting, and the lovely violet tint that springs out in the direction of the prism-edge is by contrast almost startling. Another optical feature is that spodumene is markedly excited by ultra-violet rays, and kunzite also phosphoresces under the influence of radium.

In consequence of the marked dichroism possessed by kunzite, hiddenite and the coloured varieties of spodumene in general, it is essential, in order to assure the best results from a faceted stone, that the table facet be nearly at right angles to the direction corresponding to the prism-edge in the crystal. For practical purposes this will suffice, although, as was pointed out above, the maximum actinic effect is obtained in the direction inclined at an angle of about 25° to the prism-edge. In addition, great care must be exercised during the mechanical process of cutting and polishing that the extremely easy cleavage characteristic of this gemstone does not develop and either ruin the stone by splitting it or mar its appearance by the production of flaws.

Two faceted stones, a beautiful kunzite and a fine hiddenite, weighing 61·7 and 2·5 carats respectively, are exhibited in the Mineral Gallery of the British Museum (Natural History). They are depicted on plate XX, 14 and 15.

Little difficulty should be experienced in the identification of spodumene, if a careful measurement be made of its principal refractive indices. The gemstones lying near it in this respect, euclase and fibrolite, differ from it in colour, and are respectively lower and higher in specific gravity. It may, too, be remembered that the characteristic tint of kunzite is unmistakable.

Spodumene is valuable to commerce as the principal ore of lithium. It is one of the mineral constituents of pegmatite dykes in the granite of many parts of the world: Scotland, Ireland, United States, Madagascar, etc. The opaque masses attain to very large sizes; the largest such crystal known is one found in South Dakota, U.S.A., which measured about 42 feet in length and 6 by 3 feet in section (13 × 2 × 1 m.) and was estimated to weigh 65 tons. Hiddenite was discovered in 1881 in Alexander County, North Carolina, U.S.A. No such deep emerald-green spodumene has been seen elsewhere; the hiddenite from Madagascar is a pale yellowish-green in colour. Kunzite came to light in 1903 at Pala, San Diego County, California, U.S.A., in all shades of colour ranging from pale pink to deep lilac-blue and in crystals as much as 150 carats in weight and accompanied by yellow spodumene. Other localities for kunzite in the United States are Cohuila Mountain in Riverside County, California, where stones of rather pale shades are associated with beryl and tourmaline, near Branchville in Connecticut, and in Maine. Both kunzite and clear, lemon-yellow spodumene are yielded by Minas Gerais, Brazil, and by Madagascar.

TAAFFEITE

Taaffeite [1] is a new mineral which was discovered in an unprecedented manner owing to the acumen of Count Taaffe, after whom in consequence it has been named. In 1945 he noticed among a parcel of cut stones which he had acquired as spinels one that showed slight but

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[1] C. J. Payne, 'A new gemstone,' *The Journal of Gemmology*, 1951, vol. III, pp. 77–80. B. W. Anderson, C. J. Payne and G. F. Claringbull, 'Taaffeite, a new beryllium mineral, found as a cut gemstone. With microchemical analysis by M. H. Hey,' *Mineralogical Magazine*, 1951, vol. XXIX, pp. 765–72.

unmistakable signs of doubling of the edges of the back facets when viewed through the table. Not having suitable instruments for closer study, he sent the stone to the Precious Stone Laboratory in London, where its physical constants were determined and found to differ from those of any known mineral. The stone was accordingly transmitted to the Mineral Department of the British Museum for still closer study by means of X-rays and microchemical analysis, with the consent of the owner a small piece being sawn from it for the purpose. In chemical composition taaffeite was found to lie midway between spinel and chrysoberyl, having a formula corresponding to $MgBeAl_4O_8$. Its pale mauve colour is due to a trace of iron. It crystallizes in the rare trapezohedral class of the hexagonal system, and has uniaxial birefringence, negative in character, the ordinary and extraordinary refractive indices being 1·723 and 1·719 respectively. Its specific gravity is 3·62, and hardness 8 on Mohs's scale. A second cut stone, which came to light at the Laboratory in 1949, is paler in colour, and has slightly lower refractive indices, namely 1·7206 and 1·7167. Since in both instances the stone had already been cut, the origin of taaffeite is not known, but may plausibly be conjectured to be the gem-gravels of Ceylon.

WILLEMITE

Long familiar as an important ore of zinc, willemite recently found a precarious footing among gemstones, when it was discovered in clear pale-yellow pieces large enough for cutting purposes. It was named in 1830 after William I, King of the Netherlands.

Willemite in chemical composition is a zinc silicate, corresponding to the formula Zn_2SiO_4, but ordinarily manganese replaces part of the zinc. If pure, it would be colourless, but it is often stained various shades by the mineral colouring agents present, the tint of the yellow stones being due to iron. Willemite crystallizes in the rhombohedral class of the trigonal system, and has a direction of easy cleavage parallel to the basal face. The double refraction is uniaxial and optically positive, the values of the ordinary and extraordinary refractive indices being 1·691 and 1·719 respectively. The lustre is vitreous, inclined to resinous. The light-coloured varieties fluoresce a pale-green tint when excited by ultraviolet rays or phosphoresce after exposure to magnesium light or the radiations from radium. The specific gravity is 3·89, but rises with increasing percentages of manganese to 4·18. Willemite is soft, the hardness corresponding to $5\frac{1}{2}$ on Mohs's scale. It is one of the minerals associated with franklinite at the Franklin Furnace mines in New Jersey, U.S.A.

ZINCITE

A highly prized curiosity in the shape of lustrous red gem material has very occasionally been provided by the rare mineral known as zincite from its metal constituent. Both because of its perfect cleavage and because of its comparative softness it will not stand up to rough usage.

Zincite is the red oxide of zinc, corresponding to the formula ZnO, but usually small amounts of the corresponding oxide of manganese, MnO, are also present. It commonly occurs in foliated masses or in irregular grains, and crystals are exceedingly rare. The colour is deep red and occasionally orange-yellow, and is no doubt caused by the manganese content. Zincite is one of the few substances crystallizing in the dihexagonal-pyramidal class of the hexagonal system, in which there is a vertical hexagonal axis and six vertical planes of symmetry, but no horizontal plane or centre of symmetry. In harmony with the crystal symmetry it has uniaxial double refraction; the values of the ordinary and extraordinary refractive indices are 2·013 and 2·029 respectively, the birefringence therefore being 0·016, and its sign is positive. In keeping with its high refractivity its lustre is almost adamantine. The specific gravity is 5·68 for crystals of zincite. The hardness is 4 to 4½ on Mohs's scale; that is, it is on the whole slightly harder than fluor. There is a perfect cleavage parallel to the basal face *c* (0001).

Gem material of zincite has been found only at the well-known mines of Franklin Furnace, Sussex County, New Jersey, U.S.A. A beautiful clear, red, emerald-cut stone, 1·155 carats in weight, is in the Mineral Collection of the British Museum (Natural History).

EKANITE

In 1952 a dark green cabochon-cut gem, showing faint asterism, was sent for examination in this country by F. L. D. Ekanayake of Ceylon, who believed that it was a new mineral species. The stone proved to be amorphous, and might therefore have been a glass, but it contained a large number of inclusions which were oriented in two directions at right-angles. The radioactive element thorium was shown to be present in considerable amounts. A cooperative study eventually proved it to be a new mineral in the metamict state (p. 355), and it was named from its discoverer. The formula is given as $(Th,U)(Ca,Fe,Pb)_2Si_8O_{20}$. The refractive index is 1·597 and specific gravity 3·280. An ordered crystalline structure with tetragonal symmetry (accounting for the preferred orientation of the inclusions) can be produced by heating to 1000° C. Further specimens have since been found in gem gravels at Eheliyagoda, Ratnapura.

XXXV

NATURAL GLASS

In this chapter are discussed the three kinds into which the natural glass that has been found on the surface of the earth may be sorted. None of them is of consequence in the modern world, whether as gem material or for other purposes; but to ancient man before the invention of artificial glass obsidian, which was the only kind known to him, was of transcendental importance as the material for tools and weapons as well as for ornaments. The remaining two kinds—tektite and silica-glass—are of much more recent discovery, the earliest of them, a variety of tektite, going back only just into the eighteenth century, and have been of far smaller utility; but the problem of whence they have come is one of absorbing scientific interest, which still calls for complete solution.

The coloured materials provided by obsidian and to a much smaller degree by tektite have occasionally been cut, for they are of restful shades which are pleasant to the eye. The silica-glass from the Libyan Desert, on the other hand, although it occurs in large and clear pieces, is hardly worth the trouble of cutting, since its colour is unattractive, and owing to its low refraction and small colour-dispersion it has no life or fire when faceted.

A. OBSIDIAN

The natural glass, known as obsidian, is the result of the cooling of a volcanic lava which has been too rapid to permit of its crystallization as a rock; had solidification of the molten mass proceeded with sufficient slowness, the product would have been a rock consisting mainly of quartz, feldspar and mica. The Romans were well acquainted with this natural glass and called it obsianus, a name for which various derivations have been suggested. For some obscure reason the name appeared in the form obsidianus in all the early printed editions of Pliny's *Natural History*, and thus misspelt was adapted into French and other languages. The corrupt form has been so long accepted that it would be idle to think of correcting it at this late date.

Obsidian, being a mixture, is extremely variable in chemical composition. It is rich in silica, the percentage amount of which varies from about 66 to 77, with a percentage amount of alumina usually between 10 and 18. Usually it is so dark as to appear black and opaque; other colours that have been met with are grey, yellow, brown and red. Varieties which have been cut are fairly transparent, showing shades of yellowish-brown or greenish-brown. Generally its texture is uneven, striated or spotted owing to incipient crystallization, and small vesicles are often present due to the formation of steam. In common with all glasses, obsidian is vitreous in lustre and isotropic in the character of its refraction, although there may be slight local double refraction owing to strain. The refractive index varies from 1·48 to 1·51, and the specific gravity from 2·33 to 2·47 approximately; the hardness is the same as for window-glass, namely, 5 on Mohs's scale. It may be noticed that basalt-glass has higher ranges, namely, 1·58 to 1·65 for the refractive index and 2·70 to 3·00 for the specific gravity.

Water-worn, bottle-green glass, which has been picked up on the seashore, for instance in Cornwall, is often sold locally under the misnomer of 'obsidian'. It can easily be recognized by its transparency; moreover, it has perceptibly higher refraction and specific gravity. A more obvious fraud is to offer cut specimens as obsidian, which, being bluish-green in colour, do not even pretend to be the correct tint.

It was the property of obsidian, which it shares with ordinary glass, to break with a keen cutting-edge that made it so invaluable to primitive people before metal tools were thought of. For all purposes of peace and war—for mirrors, masks or figures, for axes or knives, for heads of arrows or spears—obsidian was extensively used by the ancient inhabitants of Mexico; vast mines of great antiquity still exist in Hidalgo State, and other mines are known in Queretaro State. Other important localities are Lipari and Volcano islands, north of Sicily, and Obsidian Cliff in the Yellowstone National Park, U.S.A.

B. TEKTITE

We pass now to a different kind of natural glass. Obsidian occurs in such close connexion with volcanoes that no doubt has ever been felt about its volcanic origin. Whence the group of natural glass known as tektite has come has given rise to much speculation; many diverse theories have been advanced, but the question still remains obscure. The name of the group is derived from the Greek word *τηκτός* (melted).

The occurrence of numerous small pieces of glass near the Moldau

River in Bohemia, and also farther east in Moravia, was known as far back as 1787. The glass was called moldavite after the name of the river. In view of the absence of signs of volcanic activity in this area it was realized that this glass must be different from obsidian in its origin. The plausible theory was put forward that in moldavites we had lumps that had been left behind on the site of prehistoric glass factories, but it had to be abandoned when a century or so later glass of a similar nature was discovered over extensive areas far removed from the centres of ancient civilization, since it was clearly incredible that the primitive races inhabiting these regions could have acquired the art of glass-making, then forgotten it, and left no traces of it other than this mysterious glass.

An enormous number of small pieces of natural glass, mostly button-shaped, has been found distributed all over the south of Australia as well as in Tasmania; this glass is consequently known as australite. Other glass of a similar nature was discovered in Billiton Island, lying between Sumatra and Borneo, and is called billitonite. Its area of distribution appears to extend to Java, Borneo and Malaya.

Similar glass has been found in other countries: Philippine Islands, Indo-China, Colombia and Peru. In certain instances, however, the question has been raised whether the glass is not really of volcanic origin and therefore obsidian. No locality names have been bestowed upon these occurrences.

There is clearly only one convincing explanation of such a distribution as that of tektite, which is so completely unconnected with the character of the earth's surface, and that is that all such natural glass has fallen from the skies; but that in no way means that the problem is solved. Solid bodies have been seen to fall, and are known as meteorites. They differ in some important respects from terrestrial objects. Their composition is in varying proportions, partly metallic and partly stony; the former consists mainly of a mixture of two alloys of nickel and iron, and the latter of pyroxene, olivine and a little feldspar. More numerous bodies of precisely similar characters have been discovered on or near the surface of the earth, and it may confidently be assumed that they likewise have come from outer space, but in the distant past long before the days of writing, or even before the existence of man, so that there is now no record of the fall. The tektites, however, are altogether unlike meteorites both in structure and in chemical composition, and there is no record of a tektite having been seen to fall; there must therefore remain an element of doubt about the cosmic theory, although it is the one generally accepted.

There is evidence that the tremendous heat generated by the impact of an enormous meteorite upon the surface of the earth has resulted in the fusion of the mineral material near the site of the fall; for instance, in the desert by Wabar in Arabia the sand has been fused in this way. A theory on these lines does not explain the tektites, because they are in general unrelated to the rocks near which they are found. Other theories are that tektites are material originally erupted from the moon's long-since extinct volcanoes or derived from the tails of comets, or have resulted from the action of humic acid upon the underlying rocks under certain climatic conditions.

Moldavites are transparent and bottle-green to greenish-brown in colour, and alone among the tektites provide gem material, which also passes under the names 'bottle-stone' and 'water-chrysolite'. Tektites from Borneo are sometimes dark-brown and from Colombia nearly colourless, but generally they are black and opaque. They are always characterized by surface-markings, due probably to a whirling motion when falling through the air, and, especially in the case of the australites, are often button-shaped. Their composition is rich in silica, the percentage amount varying from about 70 to 77 with a corresponding range of alumina from about 15 to 10. The refraction is, of course, isotropic, and the range of the values of the refractive index is 1·48 to 1·52, and of the specific gravity 2·30 to 2·50; the hardness is about 5½ on Mohs's scale.

A different kind of tektite has been found in the Jukes-Darwin mining field near Queenstown in western Tasmania; it is therefore called darwin-glass or queenstownite. It is much richer in silica than tektites generally, the percentage amount ranging from about 86 to 90. and poorer in alumina, the corresponding range being about 8 to 6. The colour is white or olive-green, and deepens to black. The pieces vary in size from tiny drops to fragments 2½ inches (6 cm.) in length, and generally contain vesicles. The specific gravity varies from 1·85 to 2·30, It will be observed that in these physical properties darwin-glass lies below the usual range of tektites.

C. SILICA-GLASS

As we have seen, all natural glass is rich in silica, and in the series considered in this chapter it has become sensibly richer until it culminates in the silica-glass, containing nearly 98 per cent of silica, which was discovered at the end of 1932 over an extensive area in the Libyan Desert by the Egyptian Desert Survey. In size this kind of natural glass far exceeds any other, the lumps found ranging up to 10 lb. (5 kg.) in weight, and it is, moreover, much more transparent and is capable of yielding large cut stones. The colour is a pale yellowish-green.

The physical properties are almost identical with those of the artificial silica-glass (p. 373), the slight divergences being due to the impurities present: refractive index 1·462, colour-dispersion (*B–G*) 0·010, specific gravity 2·21, hardness 6 on Mohs's scale. With such low refraction and small colour-dispersion no life or fire can be expected in a faceted stone, and the tint is not one which is generally admired.

Section C. Ornamental Stones

In this section are grouped together those materials which normally lack transparency and therefore owe their attraction to the colour or the texture that they possess, or to a combination of these two qualities. Most of them are valued for their colour, turquoise, jade and lapis-lazuli being conspicuous examples; while in agate the attraction lies largely in the pattern and in malachite in both colour and pattern.

XXXVI

CHALCEDONY

The compact varieties of silica which are grouped under the general title of chalcedony have been described as a mixture of silica in minute crystals (quartz) and hydrated silica in an amorphous form (opal). It now seems probable that they are composed entirely of microcrystalline quartz with sub-microscopic pores containing water or dilute saline solutions. In colour, appearance and texture they vary considerably, and, inasmuch as all three characters have been made criteria for differentiating a variety, a host of names have come into use, none of which is susceptible of strict definition. On the whole these compact varieties may be divided into two groups: chalcedony, in which the structure is concretionary and the colour comparatively uniform, and agate, in which the structure is in the form of bands, varying greatly in width and colour. Each group includes many kinds to which names have been given. These names go back a long way in history and have not all remained constant in meaning.

The term chalcedony is commonly used for pieces of a greyish tinge, because the coloured pieces have names of their own. The origin of the word is doubtful. The plausible suggestion that it has come from Chalcedon, a place in Asia Minor, and thus means a Chalcedonian stone, is no longer accepted. It may be noted that the variant, carcedonius, in the Vulgate edition of the Old Testament, suggests a connexion with the famous city, Carthage (Καρχηδών), in North Africa. The scanty descriptions of the stone that have come down to us from ancient times point to its having been green in colour, and this sense of the word continued to the seventeenth century and overlapped the modern usage, which can be traced back only to the beginning of the sixteenth century.

Cornelian, or carnelian, is a reddish or yellowish-red chalcedony. Cornelian comes from the medieval Latin word *cornum* (cornel-berry or cornelian cherry). Carnelian is a perverted form that was introduced in the fifteenth century, because of the mistaken idea that it originated from the Latin word *carneolus* after *carnem* (flesh). Carneol, with the same derivation, is a name that has been introduced in modern times for dyed pink chalcedony. Sard is the brownish variety, but, as used in the Bible, it appears to have referred to a red stone. The word comes through the Latin from the Greek word *σάρδιος*, a form of *Σάρδεις* (Sardis), which was the capital of Lydia in Asia Minor, and was no doubt used for a local product. Bloodstone, or heliotrope, is a chaldedony speckled with red. The former name is obviously related to its appearance; bloodstone was once used as an amulet in the belief that it would stop bleeding. The German bloodstone (*Blutstein*) is, however, haematite. Heliotrope comes from the two Greek words *ἥλιος* (sun) and *τρόπος* (direction), and was originally applied to a green chalcedony with such an extent of red patches that, when placed in water in the face of the sun, the whole appeared red. It may be remarked that in botany the word is used for flowers that turn to the sun. Occasionally heliotrope has wrongly been called haematite. Jasper is an impure opaque quartz, heavily impregnated with impurities, and according to their nature coloured red, yellow or brown; in ribbon-jasper the colours run in stripes and in Egyptian-jasper in zones. The name is derived through the Latin from the Greek word *ἴασπις*, which is of oriental origin but unknown significance. In ancient times it was used in a different and wider sense for translucent chalcedony of all hues except the red of cornelian, green being the one most esteemed.

Some prase is a dull, leek-green chalcedony; as was mentioned in an earlier chapter, the name is also used for quartz, coloured green by actinolite fibres. Chrysoprase is the apple-green variety, coloured by nickel oxide; the name comes from the Greek word *χρυσόπρασος* (golden-green). Plasma is a brighter green chalcedony, sometimes flecked with white spots; the name is derived through the Latin from the Greek word *πλάσμα* (thing formed, image).

Flint, an opaque, dull-coloured chalcedony, breaks with a sharp cutting edge which made it invaluable to early man as a weapon or a tool; its capacity to emit sparks when struck by steel brought it into extensive use for ignition purposes before the invention of matches and detonators. The name is derived from the Greek word *πλίνθος* (tile). Hornstone resembles flint, but is more brittle and does not fracture with such a keen edge; the name comes from the German word *hornstein*, which was given to it because of its appearance. Chert is a flinty rock; except that chert was probably a local name its origin is unknown.

Agate is a chalcedony with a peculiar banded structure. The bands are usually irregular in shape, since they conform to the shape of the cavity in which the substance was formed, and vary considerably in thickness and in colour, though they are generally of greyish shades. The name comes through the Latin from the Greek word Αχάτης, which was given to a river in Sicily, where the material was found in the time of Theophrastus. Moss-agate or mocha-stone contains dendritic or moss-like inclusions of some fibrous material, such as manganese oxide; the former name has an obvious origin, and the latter is derived from the port, now called Mokha on the Red Sea coast of Arabia, once famous but now little used. In ruin-agate and fortification-agate cut and polished slices show markings suggestive of these prefixes. The so-called 'Icelandic-agate' is really obsidian. Onyx is an agate with regular bands in sharply contrasted colours; the name comes through the Latin from the Greek word ὄνυξ (nail). When uniformly black, it is called black onyx. Sardonyx is an onyx with red bands (sard).

We have remarked above that the composition of chalcedony is chiefly silica and a varying amount of water, but some impurities are always present. In spite of the irregular nature of its structure slight double refraction is usually discernible with the refractometer; the values of the refractive indices lie between 1·533 and 1·539. The specific gravity varies from 2·58 to 2·64 according to the impurities present and the nature of the texture. The hardness is about 7 on Mohs's scale of hardness. Chaldedony, and especially flint pebbles, when rubbed in the dark, will emit a shower of sparks, the phenomenon known as triboluminescence (p. 141).

Every kind of chalcedony is more or less porous, and in commerce advantage is taken of this property to impart to pieces tints much more vivid than those bestowed upon them by nature. To this practice no objection need be raised, provided that no attempt be made to mislead the public as to what has happened. Unhappily, traders are apt to invent names which are at least deceptive, if not entirely wrong. Thus, such terms as 'emeraldine', or 'blue moonstone' for chalcedony, stained green or blue; 'German', 'Swiss' or 'false' lapis for jasper, stained blue; and chrysoprase for agate, stained green, are strongly to be deprecated, and have now been banned by international agreement. Pieces, stained green by a chromium solution, appear red when viewed through a Chelsea filter, and might therefore at first sight be mistaken for emerald; if, on the other hand, the green colour be due to staining by nickel compounds, they do not display this phenomenon.

Practically the whole of the agate so widely used for umbrella handles and similar articles has been artificially coloured. If the colouring agent be an aniline dye, the resulting tint cannot be expected to be at all stable, and will speedily begin to fade on exposure to sunlight. Being common and fairly hard, agate is found very useful in the laboratory; for instance, for supporting the knife-edges of delicate chemical balances and, in the form of pestle and mortar, for grinding material to a powder. The agate cutting and staining industry is mainly at Idar-Oberstein, Germany.

Black and white onyx was much used for cameos at one time, when such articles were fashionable, the cutting being so arranged that a white picture was projected against a black background. Mention has already been made of the value of flint to early man; there still remains another important function, namely, that of providing local building material which withstands the passage of time unscathed.

Chalcedony is commonly found in the cavities of volcanic rocks or as nodules in sedimentary rocks; sometimes it occurs in stalactite formation.

Agate is the only variety of chalcedony that commands a regular commercial value.

Chalcedony occurs the whole world over, but that from the area lying in northern Uruguay and extending over the border into the State of Rio Grande do Sul of Brazil, from the Deccan of India and from Madagascar, alone is systematically exploited. The nodules containing water, found in Uruguay, are known as enhydros, from the Greek word *ἔνυδρος* (holding water).

XXXVII

JADE, LAPIS-LAZULI AND TURQUOISE

JADE

Although not usually accounted among the precious stones in western civilization, jade was held in extraordinary esteem by primitive man, and was fashioned by him into all kinds of ornaments and utensils, many of them of considerable beauty, and up to the present day it ranks in the East equal to, if not above, any of the gemstones; indeed, the Chinese word *Yu*, and the Japanese words *Giyuku* or *Tama*, signify both jade and precious stones in general. According to the Chinese, jade is the prototype of all gems, and unites in itself the five cardinal virtues: *Jin* (charity), *Gi* (modesty), *Yu* (courage), *Ketsu* (justice) and *Chi* (wisdom). When powdered and mixed with water, it is supposed by them to be a powerful remedy for all kinds of internal disorders, to strengthen the frame and prevent fatigue, to prolong life, and, if taken in sufficient quantity just before death, to prevent decomposition.

Jade is a general term that properly includes two distinct minerals—nephrite and jadeite, which are very similar in appearance, both being fibrous and tough in texture, and more or less greenish in colour; but it is also wrongly applied to other minerals, which have somewhat similar appearance, such as saussurite, californite, bowenite, plasma, massive grossular and verdite. The word jade was adapted from the last word of the Spanish name for the substance, *piedra de ijada* (colic-stone), which referred to its supposed efficacy for internal disorders. It appeared in French as *l'ejade*, a feminine noun, but owing to a misunderstanding finally took the form *le jade*, from which the English word is obtained.

A. NEPHRITE

Nephrite, or greenstone as it is sometimes called, which is the commoner of the two jades, is a member of the important amphibole family of minerals, which was so named by Haüy because of the unusually variable characters of the constituent species. The name of the family comes through the French from the Greek ἀμφίβολον (ambiguous), which is derived from ἀμφί (on both sides) and βολ- or βάλ, the stem of βάλλειν (throw). Nephrite is derived from the Greek word νεφρός (kidney), the allusion being the same as for jade. The significance of greenstone obviously refers to the usual colour of the stone.

Nephrite is a member of the tremolite–actinolite series, the former name being applied to stones, white or greyish in colour, containing little or no iron, and the latter to those, green in colour, in which an appreciable amount of ferrous oxide is present. In chemical composition the series corresponds to the formula $Ca_2(Mg,Fe)_5(OH)_2(Si_4O_{11})_2$. The name tremolite was taken from Tremola valley, St Gotthard, Switzerland, and actinolite is derived from the Greek words ἀκτίν (ray) and λίθος (stone) in reference to its radiated character. It is of interest to note that the complex hornblende series also belongs to the amphibole family, and that actinolite supplies some of the asbestos of commerce.

Microscopic examination of nephrite shows the structure to consist of innumerable independent fibrous crystals, foliated or matted together, the former character giving rise to a slaty and the latter to a horny effect in the stone as seen by the unaided eye. The colour varies from grey to leaf-green and dark-green, and may be yellow, blue and black, the depth of tint varying with the relative amount of ferrous oxide in the composition; the brown streaks that are often present result from the further oxidation of the iron along cracks in the stone. A highly prized variety is known as mutton-fat jade. The crystals have monoclinic symmetry, and possess two perfect cleavages, mutually inclined at an angle of 124°; the possession of two directions of perfect cleavage, mutually inclined at angles slightly exceeding 120°, is characteristic of the members of the amphibole family, but in an aggregate of crystals this feature could, of course, only be detected if a thin section were available. In harmony with the crystal symmetry, nephrite is biaxial, the birefringence being negative in character. The refractivity increases with the relative amount of iron present. For nephrite the values of the least and greatest of the principal refractive indices vary from 1·600 to 1·614, and from 1·627 to 1·641 respectively, the maximum amount of double refraction remaining constant at 0·027; some actinolite has refractive indices somewhat higher than the two maximum values given. The coloured fibres are markedly dichroic, the green colour becoming yellowish. These optical effects may, however, be masked because of the irregularity of the aggregation of the individual crystals. The specific gravity ranges from

2·90 to 3·02. The hardness is 6½ on Mohs's scale; nephrite is therefore about as hard as ordinary glass and softer than quartz. When polished, it always assumes a greasy lustre.

Many of the prehistoric implements found in Mexico and in the Swiss Lake Habitations are composed of nephrite, but it is uncertain where the mineral was obtained. Much of the material used by the Chinese in modern times has come from the south and west of Sinkiang (East Turkestan), especially in the valleys of the rivers Karakash, Yurungkash and Keriya in the Kuen-lun Mountain range on the Tibet border, and also farther north in the districts round Kashgar and Khotan. Nephrite is also found in other provinces, namely, Shen-si, Kwei-chow, Kwang-tung, Yun-nan and Manchuria. It occurs *in situ* between hornblende-schist and gneiss, but is mostly obtained in the form of boulders from river-beds. The Chinese use every variety for carving into ornaments of all kinds, but they most highly esteem the white variety. Water-worn boulders, some of gigantic size, have been discovered in the rivers Bielaya, Kitoi, Bistraya, Sludyanka and Onot south of Irkutsk in the Baikal region of Russia, the first discovery being made by J. P. Alibert in 1850 in the Onot. A large boulder from here, weighing over half a ton (1156 lb., or 524·5 kg.) is exhibited in the Mineral Gallery of the British Museum (Natural History). A much larger mass, weighing over 2 tons (4718 lb., or 2140 kg.), was discovered at Jordansmühl, Silesia, Prussia, by G. F. Kunz, and was incorporated in the magnificent collection, formed by Heber R. Bishop, which is now in the Metropolitan Museum in New York. Beautiful greenstone occurs in New Zealand in the form of pebbles and boulders in many river-valleys in north Westland in the South Island. It has also been found *in situ* in parts of the Southern Alps and in D'Urville Island. The Maoris have long used the material for various useful and ornamental purposes, the commonest being indicated by their general name for the mineral *punamu* (axe-stone); *kawakawa* is their name for the ordinary green variety, while *inanga*, a grey variety, and *kahurangi*, a pale-green and translucent variety, are rare and highly prized. The serpentine-jade, bowenite, is also found and used. In the U.S.A. nephrite has been found near Lander, Wyoming; in Millard County, Utah; at several localities in California; and in north-western Alaska. It occurs in the Upper Lewis and Fraser rivers in British Columbia, and in the valley of the Amazon in Brazil.

B. JADEITE

Jadeite, which is by far the rarer of the two jades and is accounted by the Chinese as the choicest of all gemstones, is a member of the large and varied pyroxene family of minerals, which is akin to the amphibole family and closely related to it in chemical composition. The pyroxenes include in addition to jadeite three other gemstones: spodumene, enstatite and diopside, of which the first is closely related to it in chemical composition, as we shall see below. Haüy gave the name to the family, deriving it from the Greek words πῦρ (fire) and ξένος (stranger), in the mistaken belief that these minerals were alien to igneous rocks. The name jadeite is, of course, derived from jade, of which it is the more valuable species.

Jadeite is in colour white, grey, orange, brown, mauve, black and various shades of green to emerald-green, the colour often running in streaks through the white; the emerald-green jadeite is especially prized. The green colour is due to the presence of chromium. Jadeite is extremely tough owing to the complex interweaving of the individual crystals. These are monoclinic in symmetry and possess two directions of cleavage, mutually inclined at an angle of about 93°; the possession of two directions of cleavage, nearly at right angles to one another, is, indeed, common to all the minerals of this family. Jadeite in chemical composition is mainly a sodium–aluminium silicate corresponding to the formula $NaAl(SiO_3)_2$, with which is intermingled a varying percentage of the calcium–magnesium silicate (diopside) molecule corresponding to the formula $CaMg(SiO_3)_2$. It is biaxial, with positive birefringence, and the values of the least and greatest of the principal refractive indices are about 1·654 and 1·667, perceptibly higher than those of nephrite. The specific gravity is likewise higher, ranging from 3·30 to 3·36. Jadeite is also perceptibly harder and ranks about equal to quartz with the symbol 7 on Mohs's scale. When polished, it presents a charming dimpled appearance owing to the uneven hardness of the surface. Before the blowpipe it fuses readily to a blebby glass, more so than nephrite does. Jadeite is by far the more valuable of the two jades. A fine slab, weighing 176½ lb. (80 kg.) is exhibited in the Museum of Practical Geology, South Kensington, London.

All the finest jade still comes from the mines of the Mogaung subdivision of Myitkyina district of Upper Burma, where it has been obtained continuously since very early times. China has always absorbed practically the whole of the output, which would challenge in value the produce of the ruby mines even at their best. The jadeite occurs as boulders in the alluvial deposits on the hillsides or in the present stream beds, and is also associated with albite in pegmatite dykes in a dark-green serpentine.

According to reports, jadeite has been found in various provinces of

China and in Tibet; but, inasmuch as it has habitually been mixed and confused with nephrite, the reports are probably without foundation.

The name, chloromelanite, has been given to a jadeite, green to black in colour, which contains a considerable percentage of either or both of the iron oxides. In allusion to its colours its name is derived from the Greek words χλωρός (green) and μέλας (black). It has been found in Mexico, California, the Swiss Lake Habitations and in France.

Attempts have been made to improve the colour of jadeite by using organic dyes, but these do not penetrate to any great depth and the colour has been found to fade after a few months.

There are other greenish tough minerals which are often, though wrongly, called jade. Thus serpentine of a rich green colour, such as bowenite, sometimes passes for jade; 'Korea-jade' is serpentine (p. 455). 'Transvaal-jade' is a compact grossular garnet (p. 333); and 'American'- or 'Californian'-jade is californite, a compact variety of idocrase (p. 406). Bowenite serpentine is now being marketed from China under the misnomer 'New Jade'.

Saussurite, which has occasionally passed for a jade, is the product of the decomposition of plagioclase-feldspars, and is composed of a mixture of albite, epidote, etc. It is possessed of a tough, compact structure and a splintery fracture, and is greenish-grey to white in colour. Its specific gravity varies from 3·0 to 3·4, and its hardness from $6\frac{1}{2}$ to 7 on Mohs's scale. Since in its altered form it is made up mainly of zoisite, the refraction is about 1·70, rather higher than for jadeite. It was originally found near Lake Geneva and was then named after H. B. de Saussure (1740–99), but occurs also in many other localities where similar metamorphism has taken place, such as the Lizard, Corsica, Lake Superior and various places in Italy, Germany and elsewhere. Verdite, another jade substitute, is a beautiful, green rock, mainly composed of the green mica, fuchsite and clay, which occurs in the Barberton district of the Transvaal, South Africa; it is known as 'Transvaal-jade' or 'African-jade'. Jade-like material is also supplied by hornblende, an important member of the amphibole family, to which nephrite itself belongs, and by fibrolite (p. 404) and pectolite. The last of these is a zeolitic mineral, which in Alaska occurs in tough masses that have been carved into ornaments and tools by the native inhabitants. In chemical composition it is a calcium–sodium silicate, corresponding to the formula $HNaCa_2(SiO_3)_2$. It possesses two directions of perfect cleavage, mutually inclined at about 95°. Its specific gravity is 2·87, hardness 5 on Mohs's scale and lustre subvitreous. Before the blowpipe it easily fuses to a white enamel. Its name is derived from the Greek words πηκτός (congealed) and λίθος (stone), in fanciful allusion to its appearance.

Jade has been crudely imitated in glass, but these imitations may easily be recognized by their vitreous, instead of greasy, lustre and inferior hardness, and sooner or later by their frangibility.

LAPIS-LAZULI

Of all the blue stones known in ancient times the lovely stone which to-day bears the name lapis-lazuli stood in highest esteem, and was used for all kinds of ornamental and decorative purposes, such as amulets, vases, boxes, etc., and as the material for mosaics and inlaid work. The present name originated in the early Middle Ages, and there can be no doubt but that in Pliny's day this stone was called sapphire, or whatever in the particular language was the equivalent word; for the following is his description: 'For sapphiros, too, is refulgent with spots like gold. It is also of an azure colour, though sometimes, but rarely, it is purple.'[1] In these few words he presents a faithful picture of lapis-lazuli, in colour blue deepening occasionally to purple and characteristically dotted with bits of pyrites, which has a tint not unlike that of gold.

The name of the stone, lapis-lazuli, is a medieval Latin form and means lazulus stone. Lazulus was adapted from the Arabic word (*al-*) *lazward*, which was used for the sky and more generally for anything blue. Subsequent adaptations have given rise to considerable confusion, which still persists. Thus, another late Latin form was *lazurius*, and from the same origin we have both lazulite and lazurite. To heighten the confusion, it was supposed that the initial letter was part of the Arabic article and was accordingly dropped in the Old French word *azur*, which latter became azure. This term was at first applied to lapis-lazuli—as, for instance, by Chaucer: 'A broche of golde and asure'[2]—but ultimately in the form, azurite, was used for the blue copper carbonate (p. 441). To lessen the confusion it would be as well if the name lazurite were dropped; it is really not necessary, since it may be regarded as a variety of haüynite.

Lapis-lazuli is a rock consisting chiefly of a blue mineral, haüynite, a brassy-yellow mineral, pyrites, and a white mineral, calcite, together

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[1] 'Sapphirus enim et aureis punctis collucet. Caeruleae et sapphiri, raroque cum purpura.' Loc. cit., book 37, ch. 9.

[2] Troylus, iii., 1321.

with small relative amounts of other minerals: diopside, mica, etc. Its beauty lies wholly in the blue mineral, and the degree of beauty is a measure of the extent to which this mineral is present in the stone. The stone may to the unaided eye appear an even shade of blue or it may be white streaked by blue, and it is frequently sprinkled with small pieces of pyrites without crystal form. In ancient times the brassy-yellow spots were thought to enhance the beauty of the stone, but to-day they are avoided if possible. They have, however, been simulated by gold fillings in some examples of the imitation lapis-lazuli made from sintered synthethic blue spinel which has been produced in Germany.

Lapis-lazuli must not be confused with lazulite, which is an entirely different mineral, being a basic magnesium–iron–aluminium phosphate, and having entirely different characters, except for some similarity in colour, which was the sole excuse for the name. Further, it should be remarked that the so-called 'German', 'Swiss' or 'false' lapis is jasper which has been artificially stained. Stains are also used to improve the appearance of poor-coloured lapis-lazuli.

Haüynite, or haüyne, is a member of an isomorphous family of minerals, blue in colour and cubic in symmetry, which are closely related, the other members of the family being sodalite and noselite, or nosean. Haüynite is named after the great Abbé Haüy, and noselite after K. W. Nose (1753–1835); sodalite was so named because it contained sodium. All three are in chemical composition sodium–aluminium silicates, corresponding to the formulae: haüynite,

$$(Na,Ca)_{4-8}(S_3,SO_2)_{1-2}(Al_6Si_6O_{24});$$

sodalite, $Na_8Cl_2(Al_6Si_6O_{24})$; noselite, $Na_8(SO_2)(Al_6Si_6O_{24})$. Some of the sodium, especially in haüynite, may be replaced by calcium, and in lapis-lazuli some isomorphous intermingling of the other two species with haüynite occurs. All three minerals have vitreous lustre.

Haüynite has a refractive index varying from 1·496 to 1·506, specific gravity varying from 2·44 to 2·49, and hardness corresponding to the symbol 6 on Mohs's scale. The figures for the refractive index and specific gravity for sodalite and noselite are appreciably lower, being 1·483 and 2·30, and 1·495 and 2·30 respectively; their hardness is the same, namely 6. Their crystal habit is usually obscure, but sometimes takes the form of dodecahedra or octahedra, which may be complexly twinned. All three minerals are decomposed by hydrochloric acid, and have dodecahedral cleavage.

Since the specific gravity of pyrites and calcite is 4·94 and 2·72 respectively, lapis-lazuli may be expected to have appreciably higher values than those given above for haüynite. In fine pieces pyrites is present, if at all, in small amounts only, and the specific gravity normally ranges from 2·75 to 2·90, but it may vary from 2·45 to 2·94. For isolated dodecahedral crystals the specific gravity is 2·53 approximately. The sintered spinel imitation has, of course, quite distinctive properties, with a refractive index of 1·72, hardness 8 and specific gravity 3·6.

In occidental jewellery lapis-lazuli usually takes the form of beads, but it may be cut into plates; in the East it is carved into all sorts of objects. In ancient times in a powdered form it provided the durable pigment ultramarine, and to it is due the glorious blue hues in the Old Masters, which have throughout the ages been universally admired; but in modern times it has been replaced by a synthetic product resulting from the fusion of kaolin with sodium carbonate and sulphur. In the business world this gemstone is often known elliptically as lapis.

By far the oldest and most famous of the lapis-lazuli mines are in a black and white limestone at a place near Firgamu on the upper part of the Kokcha River, a tributary of the Oxus, in the Badakshan district of Afghanistan, which is difficult of access and therefore not well known; both ruby and spinel have been found in the same region. These mines have been worked off and on for upwards of 6000 years, and there is little doubt but that all the lapis-lazuli of the ancients, which they knew as sapphire, really came from them, although various other localities have been named; the latter were probably the marts and mistaken for the place of origin.

Lapis-lazuli has long been known in a dolomitic limestone near various streams at the southern end of Lake Baikal in Siberia. Deposits of it have been reported from the Ovalle Cordillera, Coquimbo Province and also farther north near Antofagasta in Chile, the former being the more important of them. Other localities that may be mentioned are the Dattaw Valley near Mogok in Upper Burma, Italian Mountain in the Sawatch Range, Colorado and Cascade Canyon in San Bernardino County, California.

TURQUOISE

Turquoise owes its name to the French word for Turkish, and is really an elliptical form of *pierre turquoise* (Turkish stone). Whether it was so called because it was believed to have come from Turkestan or because it was marketed from Turkey is conjectural. Turquoise and other green phosphate minerals resembling it in appearance were no doubt included by Pliny among the three stones of similar names—callais, callaina and callaica—which he describes at considerable length. Thus he says that: 'Callais is like sapphiros in colour, only that it is paler and more closely resembles the tint of the water near the seashore in appearance.' [1] If we remember that his sapphire was our lapis-lazuli, we see that his description may be interpreted to mean a stone in general appearance like lapis-lazuli but paler and greenish in colour, and thus to refer to turquoise.

In chemical composition, turquoise is a hydrous copper–aluminium phosphate, corresponding to the formula $CuAl_6(PO_4)_4(OH)_8 \cdot 5H_2O$, in which some of the aluminium is replaced by ferric iron. When free of iron, it is blue of various shades from sky-blue deepening to a prussian-blue; the effect of the presence of iron is to impart, as usual, a greenish shade to the colour, which may predominate to such an extent that the tint is a yellowish-green or apple-green. Only the stones which are truly blue in colour are in much demand, but they are less common than those of a greenish shade. The blue stones have the merit of harmonizing fairly well with a gold setting. The colour, however, is apt to fade after the stone has long been worn. Turquoise is a concretionary mass of tiny triclinic crystals, and therefore is cryptocrystalline, and to some extent porous, in structure. For that reason turquoise rings should always be removed before the hands be washed, since, apart from the risk of introducing dirt into the stone, the water that has penetrated the surface may adversely affect the shade of colour.

In keeping with its crystal symmetry the refraction of turquoise is biaxial, the values of the least and greatest of the principal refractive indices being 1·61 and 1·65. The sign of the double refraction is positive, the mean index being near the least; its value, 1·62, is, indeed, so near that owing to the amorphous nature of the structure and its imperfect translucency the only shadow-edge normally visible in a refractometer will be at 1·61. It may be noted that even in the case of opaque stones a good reading is possible with the refractometer, provided that a surface of the stone is plane and well polished and light can penetrate at least a small way below the surface; the method of 'distant vision' (p. 66) may be used if the surface is curved. The lustre of turquoise is waxy. Its absorption-spectrum has two, hardly visible, bands centred at 4300 and 4200 Å.

Owing to the porosity of turquoise its specific gravity is not very constant. The value for the fine Persian turquoise varies from 2·75 to 2·85; since the American turquoise is more porous, the value is usually below 2·60, but it may rise to over 2·70 on absorption of water.

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[1] 'Callais sapphirum imitatur, candidior et litoroso mari similis.' Loc. cit., book 37, ch. 10.

Turquoise has a hardness of slightly less than 6 on Mohs's scale, but it takes a moderately good polish, which is fairly durable, since on account of the comparative opacity of the stones scratches on the surface are not very noticeable.

Being opaque, turquoise is normally cabochon-cut, and the steepness and contour are regulated by the purpose for which the piece is required.

Attempts are made to improve the colour of turquoise by impregnating it with prussian blue. The penetration is, however, only superficial, and the artificial coloration is usually not difficult to detect if the surface be inspected with sufficient magnification. A more successful simulation is achieved by pressing together a precipitate of aluminium phosphate coloured blue by means of copper oleate, since it has about the same appearance, hardness and specific gravity as turquoise; unlike turquoise, the artificial material fuses before the blowpipe. Cheap turquoise is often waxed to disguise the poor polish. Much 'turquoise' in the past has really been the fossil ivory, odontolite, which is described on p. 450; apart from other differences the easily distinguished organic origin of the latter is a sufficient criterion. Variscite and lazulite are minerals that occasionally supply material resembling turquoise, but their characters are sufficiently different to distinguish them.

The finest turquoise still comes from the famous mines near Nishapur, in the province of Khorasan in Persia, as it has done for hundreds of years. It is found with limonite filling the cracks and cavities in a brecciated porphyritic trachyte. Sometimes the turquoise is in too tiny fragments to be worth separate working, and it and the associated limonite are cut together and sold as turquoise-matrix. Another ancient locality is at Serabit el Khadem and the Wadi Moghara in the Sinai Peninsula, but in modern times little has come from there. Turquoise has been supplied from many localities in the United States, among them being Clark County and Esmeralda County in Nevada, where pale blue and green stones have been found; San Bernardino County, California, the stones from which are rather pale; the Jarilla mining district, New Mexico; Culberson County, Texas; Saguache, Lake, Mineral and Conejos Counties, Colorado; Virginia, in good crystals; and Arizona, where it has been found in pale greenish-blue stones.

XXXVIII

OTHER ORNAMENTAL STONES

APOPHYLLITE

The zeolitic mineral, apophyllite, is seldom likely to be met with in the jewellery world, since it is at the best only pinkish in colour and always imperfectly transparent. It was given its name because when heated before the blowpipe it exfoliates, from the two Greek words *ἀπό* (off) and *φύλλον* (leaf). In chemical composition it is a hydrated potassium–calcium silicate, corresponding to the formula $KF . Ca_4Si_8O_{12}(OH)_{16}$.

Apophyllite belongs to the tetragonal system, and possesses a perfect cleavage parallel to the basal face. Its optical characters are peculiar, because the sign of the double refraction may be either positive or negative, the values of the least and greatest of the principal refractive indices, however, remaining the same, about 1·535 and 1·537. Its colour is normally white, but may be ringed with shades of yellow, green and red. The lustre is pearly on a cleavage surface, but otherwise vitreous. The specific gravity ranges from 2·30 to 2·50, and the hardness from 4½ to 5 on Mohs's scale. Tetragonal crystals have been found at Andreasberg in the Harz Mountains, Germany, and in the Syhadree Mountains, Bombay, India.

AZURITE OR CHESSYLITE

Azurite, or chessylite, which is the blue copper carbonate, is allied to malachite (p. 449) and has a similar origin, but is not much used for ornamental purposes. The name azurite was given to it because of its azure-blue colour. As was pointed out above (p. 436), azurite, lazuli, lazurite and lazulite have a common ultimate origin. Chessylite is derived from the name of a prominent locality for the mineral.

In chemical composition, azurite is a hydrated copper carbonate, corresponding to the formula $Cu_3(OH_2)(CO_3)_2$. It is a less stable form than malachite. It belongs to the monoclinic system, but is commonly massive, and its colour is azure-blue. Optically it is biaxial with positive double refraction, the values of the least and greatest of the principal refractive indices being about 1·730 and 1·838. Its lustre is vitreous. The specific gravity varies from 3·77 to 3·89, and hardness from 3½ to 4 on Mohs's scale. In its reaction to acids and the blowpipe it resembles malachite. A banded intergrowth of azurite and malachite has sometimes been cut and polished, and has been termed 'azur-malachite'.

Azurite is an ore of copper, though not so valuable as malachite. Notable localities for it are Chessy, near Lyons in France, Bisbee in Arizona, U.S.A., Redruth in Cornwall and Katanga in the Congo.

CALCITE (MARBLE)

Marble, which is by far the best known and the most extensive of the decorative stones, is a crystalline limestone in the form of massive calcite, which in chemical composition is calcium carbonate, corresponding to the formula $CaCO_3$. The name is derived from the Latin word *calcem* (lime). If marble were absolutely pure, it would be clear and colourless, but it never is perfectly transparent and nearly always bears markings that testify to the nature of the original carbonate, as well as being coloured in patches or streaks by the many impurities that it caught up; it is these patterns and coloration that impart such a pleasing variety to the appearance of marble.

An immense number of names has been given to different kinds of marble according to their appearance or their locality. The best known statuary marble is the Parian, from Paros (Minoa) island in the Cyclades, Pentelican from Athens and Carrara from the famous quarries in Tuscany, Italy. The so-called Egyptian-marble is stained black with bitumen and veined yellow with dolomite; it has come from near Spezia, Liguria, Italy. Shell-marble consists mainly of fossil shells. One kind of shell-marble is known as lumachella, lumachelle or fire-marble, because, when light is reflected from it at the correct angle, a brilliant, fire-like iridescence is emitted, the first name being the Italian one (little snail) and the second the French form of it; it sometimes resembles opal-matrix, but is easily distinguishable from the latter by its inferior hardness and its effervescent action with acid. Choice specimens have come from Bleiberg in Carinthia, Austria and Astrakhan, Russia. Ruin-marble, which is yellowish in colour, shows in sections markings, resulting from infiltration of iron oxide, which justify its name. The calcareous deposits from water provided the alabaster of the ancients, the modern kind being gypsum (see p. 447), a much softer material. The ancient mine at Thebes, Egypt, has been almost continuously worked, and its product is still called 'Egyptian-alabaster', or alternately 'oriental-alabaster' or 'onyx-marble' from its banding; similar banded material from a cavern at Gibraltar is known as Gibraltar-stone and from Mexico as 'Mexican-onyx'. The so-called 'Brazilian-onyx' is an onyx-marble from San Luis in Argentina. Satin-spar is a name given to fibrous calcium carbonate, calcite and occasionally aragonite, and calcium sulphate (gypsum); the latter is much softer and apart from other tests the carbonates can always be recognized by the effervescence set up by acid.

In addition to its use for ornamental purposes limestone is most valuable for many of the varied requirements of civilization: as a building stone, for cements, and in the manufacture of a host of articles. The optical use of the transparent variety of calcite, called Iceland-spar, has already been discussed (p. 118).

Calcite belongs to the holosymmetric class of the trigonal system, and possesses remarkably perfect cleavage parallel to the faces of the primary rhombohedron. The values of the least (extraordinary) and greatest (ordinary) of the principal refractive indices are 1·486 and 1·658, the double refraction being uniaxial in character and negative in sign. The lustre is vitreous. The specific gravity is 2·71, but varies according to the impurities present. In hardness it is the standard for the symbol 3 of Mohs's scale.

Aragonite has the same chemical composition as calcite, but is the less stable form. Some satin-spar and alabaster may be aragonite. It belongs to the orthorhombic system, and the crystals are often twinned so as to simulate hexagonal symmetry. It has no cleavage. The values of the least and greatest of the principal refractive indices are 1·530 and 1·686, the double refraction being biaxial in character and negative in sign. The lustre is vitreous, but inclined to resinous. The specific gravity varies from 2·93 to 2·95, and hardness from $3\frac{1}{2}$ to 4 on Mohs's scale.

Aragonite differs markedly from calcite in physical properties; it also stains pink, when in a powdered form it is boiled for fifteen minutes in a dilute solution of cobalt nitrate, whereas calcite similarly treated remains white or turns yellowish, if organic matter be present, or finally blue. Gypsum (see p. 447) is entirely different in its physical properties.

CHLORASTROLITE

More than a hundred years ago this name was given to a mineral which occurs as rounded stellate aggregates of greenish fibres on the shores of Lake Superior. The name was derived from χλωρός, green, and ἄστρον, star. The aggregates weather out from adjacent lavas. They are inhomogeneous, but the main component is a hydrated calcium-aluminium silicate long supposed to be related to prehnite (p. 411). Quite recently it has been shown that the mineral is in fact pumpellyite. The irregularly coloured chatoyant material, cut in cabochon form, is unsuitable for the exact determination of optical properties; the average refractive index is about 1·70. The hardness is from 5 to 6 and the specific gravity 3·2. The best known locality is Isle Royale, Lake Superior.

CHRYSOCOLLA

Chrysocolla occurs in opaque, blue and bluish-green compact masses, with an enamel-like texture, which have occasionally been worked and polished. The Greek word *χρυσόκολλα* (gold-solder), of which the name is the transliterated form, more properly referred to borax, which it also included originally; in fact, it was used rather generally for greenish minerals, and malachite may have been among them. In modern mineralogy it is used for the alteration product of copper minerals, which is a hydrated copper silicate approximating to the formula $CuSiO_3 + 2H_2O$. Being an alteration product, it is extremely variable in composition owing to the presence of impurities. The lustre is vitreous to earthy. The hardness, too, ranges from 2 to 4 on Mohs's scale, and, when the mass contains free silica, it will scratch glass. It is very light, the specific gravity being only about 2·0 to 2·2. Owing to its opacity the optical data, which are likewise very variable, cannot conveniently be used for determinative purposes. It has been found in the upper veins of copper mines throughout the world.

DUMORTIERITE

Very occasionally the rare mineral, dumortierite, has been found in blue or violet masses, which make attractive slabs when sliced and polished. It was named after Vincent Eugène Dumortier (1801–76).

Dumortierite is a complex aluminium borosilicate, corresponding to the formula $Al(AlO)_7(BOH)(SiO_4)_3$. It crystallizes in the orthorhombic system, but is usually in the form of fibrous or columnar aggregates and not in well-defined crystals. The birefringence is biaxial in character, the optical sign being negative, and the values of the least and greatest of the principal refractive indices are 1·678 and 1·689, rising to 1·686 and 1·723 respectively in varieties rich in iron. There is marked dichroism, the principal tints being deep-blue, reddish-violet and colourless. The specific gravity ranges from 3·26 to 3·41, and the hardness is 7 on Mohs's scale.

The refractive indices and dichroism will serve to distinguish dumortierite from gemstones of similar appearance.

The localities are California, Nevada and Arizona in the United States; Norway, Madagascar, South-West Africa and near Lyons, France.

FLUOR

Fluor, fluorite or fluorspar, an extremely beautiful mineral, which nowhere has been found in such perfection as in England, long enjoyed well-deserved popularity when worked into the form of vases and other articles. The finest material, violet or purple in shade, and often pleasingly patterned in curved streaks of different shades, which was known as blue-john, came from Derbyshire, but the supply has long been almost exhausted. No more attractive objects are to be seen in mineral collections than groups of crystals of fluor which have come from England. Its name comes from the Latin word *fluere* (flow). The term was originally applied generally to minerals which were easily fusible and could be used as fluxes, but on the discovery of hydrofluoric acid in 1771 was restricted to those of them that contained fluorine, and finally to the chief of them, the mineral now known by that name. It may be noted further that the element associated with calcium in it was called fluorine after the name of the mineral. The green fluor (plate XX, 13) from South-West Africa has been wrongly called 'African-emerald'.

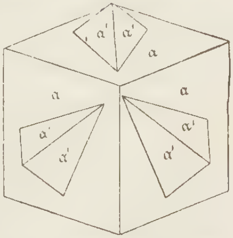

FIG. 133.—An interpenetrant twinned crystal of fluor.

Fluor, which is best known for its blue-john variety, belongs to the cubic system and is found, if in crystals, usually in the shape of cubes, sometimes modified, which are often interpenetratingly twinned about a perpendicular to a pair of octahedron faces (fig. 133 and plate XX, 17); it possesses a very easy cleavage in planes parallel to the faces of the regular octahedron. In colour it is commonly violet, blue, yellow and green, and more rarely pink (plate XX, 1) and colourless. The chemical composition is calcium fluoride, corresponding to the formula CaF_2. The refraction is single, though at times slightly double owing to local strain, and the refractive index is 1·434. The lustre is vitreous. The specific gravity is 3·18, but, if the mineral be contaminated with impurities, the value may be as low as 3·00 or as high as 3·25. The hardness is 4 on Mohs's scale of hardness.

A remarkable property of fluor is the capacity that some greenish-blue pieces have of appearing green by transmitted and blue by reflected light. Many specimens, too, will glow with a lovely violet light, which is constant in tint whatever be their colour, when excited by ultra-violet rays or others of short wave-length. This phenomenon is consequently known as fluorescence. Some fluors do not display it; it is, indeed, not characteristic of the pure mineral, but results from the presence of minute quantities of manganese and rare earths.

After the exhaustion of the blue-john deposits, fluor has practically disappeared from ornamental use, but it might well be resuscitated in the faceted form, in spite of its low refraction, easy cleavage and softness, so delightful are the colours that are to be seen; possibly the most pleasing are the yellow and green stones. With care faceted fluors should retain their appearance for years, if worn as pendants or ear-rings, or generally in such a way that they are not subject to constant rubbing.

Fluor finds a large industrial use as a flux in the manufacture of steel, a source of hydrofluoric acid and an ingredient of opalescent glass and certain enamels. Owing to the low refractive index, 1·434, and small dispersion, 0·0045 for the *C–F* interval, as compared, for example, with 1·499 and 0·0075 for the lowest glass, the colourless material is invaluable for an intermediate lens of apochromatic objectives. Because of the small quantity of colourless fluor which has been discovered, attempts have been made to decolorize some of the paler material, but without success.

A beautiful series of specimens of pink octahedra of fluor from Chamonix, which were presented in 1850 by John Ruskin, in honour of his friend, Joseph Couttet, are exhibited in the Mineral Gallery of the British Museum (Natural History), and two magnificent vases of blue-john will be found in the Museum of Practical Geology, South Kensington, London.

Fluor is a mineral that has been formed by the action of hot vapours or vapour-bearing water as it rises into cracks and crevices in the earth's crust, and is found in close association with galena, blende, quartz and barytes. Beautifully crystallized specimens have come from the north of England, Cornwall and Derbyshire. The not very common pink fluor, which crystallizes in octahedra, has been discovered in the Alps, in the St Gotthard and Chamonix areas. Good fluor has also come from Saxony, Norway and many parts of the United States. Beautiful clear emerald-green fluor is a recent discovery in South-West Africa. Green fluor, like emerald, often appears pink when viewed through the Chelsea filter, but its shade of colour is sufficiently distinct to prevent confusion.

GYPSUM (ALABASTER)

Alabaster of modern times is gypsum, the hydrated calcium sulphate, corresponding to the formula $CaSO_4 . 2H_2O$. As was pointed out (p. 442), in ancient times the material used for the ointment vases known as alabastra was mostly calcium carbonate, but some of it may have been the sulphate. The name is the Latin word *alabaster*, which was adapted from the Greek ἀλάβαστρος, or more properly ἀλάβαστος, which is said to have been derived from the name of a town in Egypt. Some satin-spar is fibrous gypsum.

Gypsum is a Latin word derived from the Greek γύψος (chalk). In crystals it is also known as selenite, which is taken from the Latin form, *selenites*, of the Greek σεληνίτης (moonstone). The name probably referred to the same mineral in ancient times, and was perhaps suggested by the soft white reflections that it gives.

Gypsum belongs to the monoclinic system, and has one direction of perfect cleavage and two others less perfect. It is often massive and foliated. The values of the least and greatest of the principal refractive indices are 1·520 and 1·530, the double refraction being small in amount, biaxial in character and positive in sign. Gypsum is notable for the effect of heat upon the angle between the optic axes which is about 95° in air at ordinary room-temperatures and diminishes to 0° at 116° C. The lustre is pearly on the best cleavage face, but otherwise subvitreous. The specific gravity of pure material is 2·32, and differs from this according to the impurities present. Gypsum is the standard for the symbol 2 on Mohs's scale; it can be scratched by the finger-nail.

Gypsum also is of great service to industry, most notably in the manufacture of plaster of Paris.

HEMIMORPHITE

This zinc mineral, though less abundant than smithsonite (p. 455) with which it is frequently associated, is occasionally found in masses stained shades of green or blue, which have been worked. Because of their general resemblance in appearance and of their occurrence in association, these two zinc minerals were confounded together by the ancient Greeks under the same name, Καδμία or Καδμεία (Cadmean stone), the Cadmeans having been the ancient inhabitants of Thebes in Greece. The Romans transliterated the word to cadmia, and in later Latin it became corrupted to calamina. It became calamine in French and in the same form passed into English.

Upon the discovery that calamine was a zinc ore and contained two distinct minerals, the one a carbonate and the other a silicate, an attempt was made to restrict this term to the latter, and a new name, smithsonite, was proposed for the former; but the more general meaning of calamine still persisted, and in order to discriminate between the two minerals the prefixed form, electric calamine, was suggested for the silicate. Owing, however, to the long-continued use of the term, calamine, for the ore and the resulting confusion in nomenclature it is best to avoid its use for either mineral. In place of calamine a new name, hemimorphite, was proposed for the silicate in reference to its remarkable crystallographic properties; that is the name adopted here.

Hemimorphite is a zinc silicate, corresponding to the formula $Zn_4(OH)Si_2O_7 \cdot H_2O$, and is usually white, only occasionally being coloured green or greenish-blue, and also brown; sometimes the colours are banded. The crystals are very interesting because they belong to a hemimorphic class of the orthorhombic system and have so obtained their name. Their symmetry consists of one digonal (twofold) axis of symmetry, which forms the intersection of two planes of symmetry, mutually inclined at right angles. There is no centre of symmetry, and the character of the two ends of the crystals is markedly different, as is revealed by their facial development and by their pyroelectric properties. If a crystal be heated and dusted with a mixture of red lead and sulphur (p. 140), the more pointed end becomes yellow and the other red; if it be twinned, the crystal appears with two red ends and a yellow girdle. The crystals have two directions of perfect cleavage parallel to the faces of the principal prism.

Hemimorphite has biaxial double refraction, the optical sign being positive, and the values of the least and greatest of the principal refractive indices are about 1·614 and 1·636. The lustre is vitreous. The specific gravity varies from 3·4 to 3·5, and the hardness is about 5 on Mohs's scale.

Hemimorphite being usually associated with smithsonite it is found at the same localities. Bluish-green pieces from Roughten Gill, Cumberland, are worth mentioning.

LAZULITE

Lazulite is a blue mineral which might be used as an ornamental stone were it better known and available in larger quantities. The origin of its name is discussed above (p. 436). Lazulite in chemical composition is an iron (magnesium)–aluminium phosphate, corresponding to the formula $FeAl_2(OH)_2(PO_4)_2$, with usually some magnesium in place of the iron. Its crystals belong to the monoclinic system, and optically it is biaxial with negative double refraction, the values of the least and greatest of the principal refractive indices being about 1·61 and 1·64. Its lustre is vitreous. It is markedly dichroic, the colour corresponding to one of the principal optical directions being colourless and to the other two azure-blue. The specific gravity is about 3·1, and the hardness varies from 5 to 6 on Mohs's scale.

Lazulite has been found in many localities, including Sweden, Austria, North Carolina, U.S.A. and Minas Gerais, Brazil.

MALACHITE

Malachite is a beautiful mineral, resembling agate in texture, which has resulted from the dissolution of copper ores and the subsequent deposition of the dissolved copper salt in the fissures and cavities of rocks; often the water, bearing the salt, has percolated slowly through the rock, and the solid that has formed as the drops evaporated has assumed the stalagmite or the stalactite form. It owes its name to the Greek word μαλαχή (mallow), in allusion to the fact that its colour resembles that of the leaf of this plant.

In chemical composition, malachite is a hydrated copper carbonate, corresponding to the formula $Cu_2(OH)_2CO_3$. Azurite is another carbonate of the same kind but with a slightly different formula; it is a less stable form since it has often been found altered to malachite. Malachite belongs to the monoclinic system, but crystals are small and uncommon; its structure is usually massive in various forms with a streaky texture. It possesses a characteristic and pleasing green colour. In harmony with the crystal symmetry the double refraction is biaxial in character, the optical sign being negative. The values of the least and greatest of the principal refractive indices are about 1·66 and 1·91; the amount of double refraction, though large, is comparatively small for a carbonate. The lustre is vitreous, inclined to adamantine. Malachite is dichroic, the three principal colours being nearly colourless, yellowish-green and deep-green respectively. The massive material is silky in lustre. The specific gravity varies from 3·70 to 3·90 approximately, and the hardness is 4 on Mohs's scale. Malachite effervesces, like all carbonates, when touched with an acid, and easily fuses before the blowpipe, the flame being coloured emerald-green.

Malachite is an extremely important ore of copper, and occurs in immense masses at the copper mines of Nizhne-Tagilsk in Siberia, Burra Burra in South Australia and Katanga in the Congo. It also accompanies the copper ores in many parts of the world, for instance in Cornwall, France, Cuba, Chile and U.S.A. Although its main use is to supply a valuable metal, in its virgin form malachite has been considerably worked for ornamental purposes. 'Azur-malachite' has been mentioned on p. 442.

MEERSCHAUM

Meerschaum, or sepiolite, is a hydrated magnesium silicate with a chemical formula approximating to $H_4Mg_2Si_3O_{10}$. Owing to its lightness and porosity, the pure white masses in which it occurs have been much sought after as the material for the bowls of tobacco pipes, though nowadays it is no longer a smoker's ambition to acquire a meerschaum pipe. At one time it served as a soap in the baths in Morocco. Meerschaum is a German word (sea-foam), which was given to it because of its appearance; sepiolite comes from the Greek word σήπια (cuttle-fish), and was selected because the bones of this fish are similarly light and porous.

Meerschaum appears to be an intimate mixture of two substances: the one amorphous, to which this name may strictly be applied, and the other, biaxial negative, which may be called sepiolite. The refractivity is about 1·52 and the specific gravity about 2·0; it may be noted that its porosity, which permits the inclusion of air, enables dry pieces to float on water. The hardness is about 2 to $2\frac{1}{2}$ on Mohs's scale.

Meerschaum is a product of the alteration of serpentines, and has been obtained mostly from Asia Minor and certain of the islands near by.

ODONTOLITE

Odontolite, or bone-turquoise, consists of the teeth and bones of mastodon and other extinct animals which have been coloured deep blue or green by impregnation with solutions of iron in the form of the mineral vivianite, a hydrous iron phosphate, corresponding to the formula $Fe_3P_2O_8 \cdot 8H_2O$. Its name comes from two Greek words ὀδοντ-(ὀδούς) and λίθος (tooth-stone).

An X-ray photograph of a powdered fragment of blue odontolite from Simorre, France, taken and studied by F. A. Bannister, was found to be identical with a standard photograph of powdered apatite from Jumilla, Murcia, Spain. Turquoise, on the other hand, yields an entirely different X-ray photograph, and consequently odontolite bears no essential relation to it.

Ivory and teeth in general are composed of organic matter as well as apatite (p. 487), and so is bone; moreover, the mineral constituent is the hydroxyl-apatite and not the fluor-apatite or chlor-apatite found in the earth's crust. Some difference from the physical properties of the mineral is therefore to be expected. Apatite crystallizes in the hexagonal system, and the values of the extraordinary and ordinary refractive indices are, in the mean, 1·637 and 1·640 respectively, but the corresponding values for hydroxyl-apatite are probably lower; at any rate the refractive index for ivory and bone is close to 1·54. Vivianite crystals are monoclinic, and the values of the three principal refractive indices are 1·580, 1·598 and 1·627, but it is doubtful if the mineral is present in sufficient amount to affect the optical characters seriously. Since apatite preponderates in odontolite, it is to be expected that its refractive index is higher than for ivory and bone; the observed values range from 1·57 to 1·63. It has been pointed out above that the observable value for turquoise is 1·61. The refractive index is therefore not of much discriminative importance, and is, moreover, not easily determined.

The specific gravity of odontolite has been carefully studied. The values obtained for three cut pieces were 3·01, 3·03 and 3·15. The specific gravity of ivory ranges from 1·70 to 1·93, and of bone from 1·94 to 2·10. For the mineral apatite the range is 3·15 to 3·27, but for the carbonate-apatite known as dahllite it is lower, namely, 3·05. The range for vivianite is 2·58 to 2·68, but the presence of this mineral is not likely to affect the value much, and it may be taken that the range of the specific gravity for odontolite is 3·0 to 3·2. Low values, such as 2·4, which have been noted, probably indicate that the corresponding pieces contain a substantial proportion of organic matter. The specific gravity of turquoise normally ranges from 2·75 to 2·85, values below this range being due to porosity; it is therefore appreciably lower than the usual values for odontolite, and thus provides a useful discriminative aid.

The hardness of odontolite corresponds to about 5 on Mohs's scale, the same value as for apatite.

Odontolite can usually be recognized by its organic structure, if the surface be sufficiently magnified by a strong lens or a microscope. It invariably contains some calcium carbonate, and consequently a fragment, if touched with hydrochloric acid, will effervesce. Turquoise, on the other hand, dissolves quietly, and, since it contains copper, the addition of ammonia to the solution imparts to it a fine blue colour; in the case of odontolite no such coloration takes place.

PYRITES AND HAEMATITE

Two opaque minerals, both containing iron, pyrites and haematite, were used in ancient jewellery. These names are of very old standing, and both come from the Greek, the former from *πυρίτης* (of fire) and the latter from αἱματίτης (bloodlike). The significance of pyrites refers to its property of emitting sparks if struck by steel. Pliny seems to have used it to include other yellow minerals such as marcasite, chalcopyrite (or copper-pyrites) and pyrrhotite. Haematite was so named by the Greeks because its red tint in thin pieces and the red streak that it leaves when rubbed on stone suggested a resemblance to solidified blood.

Pyrites, also alternatively known as pyrite or iron-pyrites, is iron sulphide, corresponding to the formula FeS_2. When fresh, it is bronze-yellow or brass-yellow in colour, and the brilliant crystals, found for instance in Elba, are very attractive. Pyrites crystallizes in the cubic system, but does not possess its complete symmetry, the crystallographic axes having twofold and not fourfold symmetry. The restricted symmetry is illustrated by a crystal form which is so typical that it is often known as the pyritohedron (fig. 134). The cube is another common form, and its faces are often striated in such a manner that the restricted symmetry is revealed. The specific gravity for fresh crystals varies from 4·84 to 5·02, and the hardness is 6½ on Mohs's scale, slightly exceeding that of steel.

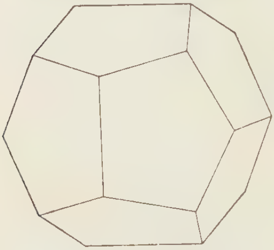

FIG. 134.—A pyritohedron.

Pyrites is cut and used in cheap jewellery, but is wrongly sold as marcasite. (This name is commonly mispronounced as 'marcazeet' in the jewellery trade; much of the material so called is not a mineral substance but polished steel or other metal.) Marcasite has the same chemical composition as pyrites, but a different form, being orthorhombic. This misuse of the name is a relic of the eighteenth century, when before minerals could be accurately discriminated marcasite and pyrites were habitually confused and the ornaments were sold as marcasite. The name comes from the late Latin word *marcasita*, but its ultimate origin is uncertain, since the Arabic word which has been thought to be its source is probably itself adopted from some European language.

Haematite (sometimes spelt hematite), or specular-iron, is iron oxide, corresponding to the formula Fe_2O_3. As used in jewellery, it is a brilliant black in colour, but in fragments and powder it is reddish, a property which serves to distinguish it from other black minerals. Haematite crystallizes in the holosymmetric class of the trigonal system. The crystals commonly consist of the primary rhombohedron, sometimes modified, or are flattened parallel to the basal face. Twinned crystals are common, and occasionally the twinning is repeated so that the resulting shape is a rosette. The specific gravity for the crystals varies from 4·95 to 5·16, and the hardness is 6½ on Mohs's scale, somewhat lower in compact varieties. In modern times it has been cut in spherical form to imitate black pearls, but it can easily be recognized by its superior specific gravity and hardness. Haematite has been used for signet rings, often with an intaglio engraving.

Haematite is one of the most important of the iron ores; pyrites, on the other hand, is almost useless for this purpose, because the metal is combined with sulphur, and it is exploited as a source of sulphur and sulphuric acid.

RHODOCHROSITE

A manganese mineral, which might fill a niche as an ornamental stone, were it more plentiful, is the carbonate, which is known as rhodochrosite from the Greek word ῥοδόχρως (rose-coloured); it bears an alternative and rather inapt name, dialogite, from the Greek word διαλογή (doubt).

Rhodochrosite is a member of the calcite group of minerals and therefore has the chemical formula $MnCO_3$. Its normal colour should be rose-red, but the effect of the isomorphous replacement of manganese by iron, calcium or magnesium is to introduce shades of yellow and brown. It crystallizes in the holosymmetric class of the trigonal system, and has three directions of easy cleavage parallel to the faces of the primitive rhombohedron. The double refraction is uniaxial in character, negative in sign, and large in amount; the values of the extraordinary and ordinary refractive indices vary from 1·597 and 1·817 to 1·605 and 1·826 respectively. The lustre is inclined to be pearly on the cleavage faces, but otherwise is vitreous. The value of the specific gravity is about 3·70 for rose-red material, but rises with increasing percentage of iron. On the other hand, the presence of impurities may reduce the specific gravity of ornamental material to as low a figure as 3·46. Its hardness is about the same as that of fluor and corresponds to the symbol 4 on Mohs's scale.

Rhodochrosite is an accessory mineral of silver, lead and copper minerals, and has been found at Capnik (Kapnik) in Hungary, Freiberg in Saxony, Leadville in Colorado and San Luis in Argentina.

RHODONITE

Rhodonite, or manganese-spar, at its best makes a handsome ornamental stone when cut and polished. In colour it is normally a shade of red, due to its manganese content—rose-pink, flesh-red and brownish-red—but turns black on alteration of the manganese, and is occasionally yellowish or greenish owing to the presence of impurities. To its best tint it owes its name, which is derived from the Greek word ῥόδον (rose). In chemical composition it is a manganese silicate, corresponding to the formula $MnSiO_3$, with usually some iron, calcium or zinc in place of some of the manganese.

Rhodonite belongs to the triclinic crystal system, and possesses two directions of perfect cleavage, mutually inclined at 87° 31½′, or nearly at right angles. Pure rhodonite has negative biaxial birefringence, the values of the least and greatest of the principal refractive indices being 1·733 and 1·744, but the addition of impurities effects a change in the optical sign to positive, and as the percentage amount of manganese falls so does the refractivity, and the corresponding least and greatest values may be as low as 1·716 and 1·728. The lustre is vitreous, but rather pearly on the cleavage surfaces. The values of the specific gravity range from 3·40 to 3·67, and of the hardness from 5½ to 6½ on Mohs's scale.

Rhodonite finds a sparing use for colouring glass and glazes. It was found in large masses near Sverdlovsk (Ekaterinburg) in the Urals, Russia, and was quarried as an ornamental stone. It is an accessory mineral at some of the manganese mines in central India. Other notable localities are the old silver mines at Butte, Montana, U.S.A., and the mines at Broken Hill, Australia.

SERPENTINE

Serpentine is an alteration product due to the decomposition of olivine and other silicates, sometimes bearing the crystal form of the original mineral, which occurs in enormous masses and on account of its comparative softness has been extensively used throughout the ages as material for cameos, intaglios and decorative purposes generally; the famous verd-antique was a green serpentine rock, veined white with calcite. In consequence of its mode of origin, serpentine varies enormously in appearance and characters, but the most highly prized pieces are some shade of green. It owes its name to its frequently mottled appearance, suggestive of a serpent's skin.

In chemical composition, serpentine is a hydrated magnesium silicate, corresponding approximately to the formula $Mg_6(OH)_6Si_4O_{11}.H_2O$, iron almost invariably replacing some of the magnesium. No doubt the presence of iron in the ferrous state is the cause of the shade of colour, usually green, displayed by serpentine. It commonly occurs as pseudomorphs, often after olivine. (A pseudomorph is a crystal of which the shape has been retained but the composition more or less completely changed.) The refraction is biaxial with weak negative birefringence, but owing to the almost amorphous character of the structure it is often almost isotropic. The refractive indices are very variable, ranging in value from 1·490 to 1·571. The lustre is rather resinous or greasy. The specific gravity ranges from 2·5 to 2·6. Since serpentine has resulted from the alteration of minerals differing in hardness, and the extent of the alteration is variable, its range of hardness is exceptionally large. Usually it extends from $2\frac{1}{2}$ to 4 on Mohs's scale, and it therefore can be easily worked with steel tools. The jade-like serpentine, sometimes called bowenite, is distinctly harder, being about 5 to 6; its specific gravity is also higher, varying from 2·6 to 2·8. This variety often passes for nephrite, one of the jades, and the so-called 'Korea-jade' or 'New jade' is really serpentine. (Bowenite was, in fact, originally described as nephrite by G. T. Bowen, and was subsequently named after him when its true nature was recognized.) Williamsite also is serpentine, of a dark green colour.

Besides its use as an ornamental stone, serpentine in its fibrous form, chrysotile, provides much of the asbestos of commerce. Chrysotile is derived from the Greek words *χρυσός* (gold) and *τίλος* (fibre), and asbestos through the Latin from the Greek word *ἄσβεστος* (unquenchable).

Serpentine has resulted from the alteration of magnesium rocks, and occurs extensively throughout the world. The Lizard and Portsoy, Banffshire are well-known localities in Great Britain.

Another alteration product, which may be mentioned here, is pseudophite (sometimes called 'Styrian jade'), belonging to the allied chlorite group of minerals, so-called because of their green colour. It owes its name to its resemblance to serpentine, being taken from *ψεύδος* (false) and *ὀφίτης* (like a serpent, the original Greek word for serpentine). It is compact and massive in texture, greenish in colour, and soft, the hardness being only $2\frac{1}{2}$. The specific gravity is about 2·76, and the chemical composition approximates to $Mg_5(OH)_6Al_2Si_3O_{11} . H_2O$. It occurs in Moravia in Czechoslovakia, Hungary and Griqualand West in South Africa.

SMITHSONITE

The important ore of zinc to which the name smithsonite was given after James Smithson (1754–1829) occasionally supplies pieces, green or greenish-blue in tint, due to staining by a copper salt, which have been worked and then to some extent resemble turquoise. The confusion that has arisen in the names of this and the zinc silicate, hemimorphite, has been described above (p. 448). The apple-green smithsonite from New Mexico was called bonamite by Goodfriend Brothers, of New York, from the French equivalent of their own name.

Smithsonite is a zinc carbonate, corresponding to the formula $ZnCO_3$, and is a member of the group of minerals that includes calcite. In colour it is usually white or greyish, the green and greenish-blue tints mentioned above not being very common. It crystallizes in the holosymmetric class of the trigonal system, but crystals are rare, and it appears commonly in compact masses. Like all members of its group it has an excellent cleavage in three directions, parallel to the faces of the primitive rhombohedron. The double refraction is uniaxial in character, negative in sign and large in amount; the values of the extraordinary and ordinary refractive indices are 1·621 and 1·849. The lustre is vitreous, but inclined to pearly on the cleavage faces. The specific gravity is about 4·30 to 4·45, and the hardness is about the same as that of apatite, corresponding to the symbol 5 on Mohs's scale.

Banded blue and green smithsonite has been found at Laurium in Greece, and more recently bluish-green, translucent material has emanated from Tsumeb in South-West Africa. Other localities which may be mentioned are Sardinia, Santander in Spain and New Mexico in the United States.

SODALITE

Sodalite, which occurs in masses closely resembling lapis-lazuli, is deserving of greater recognition than it has received. Large masses of it occur at Dungannon, Hastings County, Ontario, and at Litchfield, in Maine, U.S.A. Its chemical and physical characters are given in the description of lapis-lazuli (p. 437).

STAUROLITE

The cruciform shape of the twins in which staurolite occurs in Switzerland has led to their use in their natural form as amulets at baptisms at Basle (Basel). It is to this tendency to such twinning that the name for the species is due; it comes from the Greek word *σταυρός* (cross). Another name for it is lapis-crucifer, which has a similar significance.

In chemical composition staurolite is a hydrated iron–aluminium silicate, corresponding to the ideal formula $(OH)_2FeAl_4Si_2O_{10}$, but the crystals are always so impure that the precise composition is uncertain. It crystallizes in the orthorhombic system; the crystals are prismatic in shape, and are commonly twinned, the individual crystals crossing at right angles or nearly at 60° (fig. 135). The most valued tint is a deep-reddish brown, but the colour may be much darker until it appears to be nearly black. The crystals are at the best only imperfectly translucent, and are often quite opaque. The birefringence is biaxial, the optical sign being positive, and the values of the least and greatest of the principal refractive indices are 1·736 and 1·746 respectively. The lustre is subvitreous, inclined to resinous. The specific gravity varies from 3·65 to 3·75, and the hardness is 7 or a little higher on Mohs's scale.

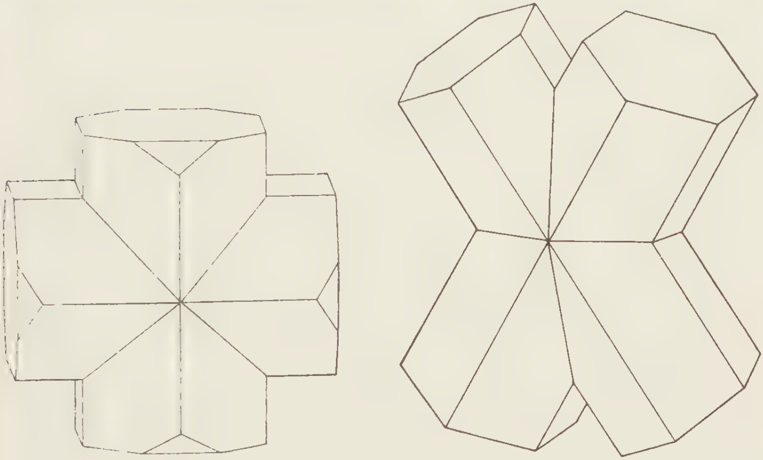

FIG. 135.—Twinned crystals of staurolite.

The characteristic twins of staurolite are unmistakable.

Staurolite has been found in many localities in various parts of the world: in Switzerland, Russia, the United States and Afghanistan; the best of them are from Switzerland, where it occurs with kyanite.

STEATITE

Steatite, or soapstone, is the massive variety of talc, the hydrated magnesium silicate corresponding to the formula $Mg_3(OH)_2Si_4O_{10}$, and in colour is white or grey, often tinged with shades of green or red. Because of its softness it has a soapy feel and is therefore called soapstone; steatite has a similar significance, being derived through the Latin from the Greek word στεατίτης (tallow-stone). The mineral name talc has been taken from the French, and is an adaptation of the medieval Latin word *talcum*. The latter comes from the Arabic term *talq*, which was used by the Arabs and medieval writers for shimmering minerals generally and included many others besides the modern talc, such as mica and selenite (gypsum); even now in commerce talc may still be used for mica.

Talc is monoclinic, but usually occurs in compact masses. The values of the least and greatest of the principal refractive indices of talc are about 1·540 and 1·590, the double refraction being very nearly uniaxial and negative in sign. The lustre is inclined to pearly. The specific gravity is about 2·75, being necessarily affected by the impurities present. Talc is one of the softest of minerals and was selected by Mohs as the standard for the symbol 1 on his scale; massive pieces may be appreciably harder because of the impurities present.

Since soapstone is so easily cut with a knife, the Chinese employ it extensively for carving into images and other objects. Owing to its incombustibility and imperviousness to electricity it serves a variety of purposes in the electrical industry. Powdered talc is used as a lubricant, in plasters and as a filler in paper, etc., and is most generally familiar in the form of toilet powder and French chalk.

Talc is a secondary mineral that has been produced as the result of the alteration of rocks containing magnesium, and occurs extensively all over the world.

Besides talc there are a few other minerals which provide similar soft compact material suitable for carving. Most of it is called agalmatolite, from ἄγαλμα (image) or pagodite, from pagoda, from its extensive use by the Chinese for carving into the form of images, pagodas, etc. It has a more prosaic use as the material for slate-pencils, and is consequently known also as pencil-stone.

Some agalmatolite is steatite. Some is a silica-rich variety of pinite, which received its name from the Pini mine, at Aue in the Saxon Erzgebirge, where it was found late in the eighteenth century. Pinite has resulted from the decomposition of cordierite especially and many other minerals such as spodumene, scapolite, nephelite and feldspar. Its composition is consequently very variable, but it approximates to that of muscovite (a variety of mica). The additional silica in agalmatolite may be from quartz or feldspar. The colour is usually greyish shades of green, brown or yellow. The hardness varies from 2½ to 3½, and the specific gravity from 2·78 to 2·81; owing to the softness the lustre is waxy.

Some agalmatolite is the compact variety of pyrophyllite, which owes its name to its faculty of exfoliating on heating, from the Greek words πῦρ (fire) and φύλλον (leaf). Pyrophyllite is a hydrous aluminium silicate, corresponding to the formula $Al_2(OH)_2Si_4O_{10}$. The agalmatolite is white, grey or greenish in colour, very soft, the hardness being about 1 to 2 on Mohs's scale, and is consequently greasy to the touch. The specific gravity is about 2·8 to 2·9, and the values of the least and greatest of the principal refractive indices are about 1·552 and 1·600, the sign of the birefringence being positive; the crystal symmetry is monoclinic. Some pyrophyllite is foliated in character. The compact variety occurs in large beds in the United States.

A soapstone is also provided by saponite, so called from the Latin word *sapo* (soap), which is an impure hydrous aluminium silicate. When fresh it is as soft as butter but becomes brittle on drying. The colour is white to greenish, bluish or reddish, the refraction is biaxial with negative sign, the values of the least and greatest of the principal refractive indices being about 1·48 and 1·52, and the specific gravity varies from 2·24 to 2·30. Saponite has been found at the Lizard, in Scotland and also in Michigan and Ontario in North America.

The so-called saponite from Plombières, France, is a clay, montmorillonite, which takes its name from one of its localities, Montmorillon in Vienne, France. It is very soft, and disintegrates in water. The specific gravity and refractive index are about 2 and 1·52 respectively, and the colour is white to reddish or greenish. Montmorillonite is a clay mineral, a hydrous aluminium silicate. The word kaolin, which is used for china-clay, is a corrupt form of the Chinese name *Kauling* (high ridge), of a hill near Jauchau Fu, where it has long been known as the material for porcelain.

STICHTITE

Stichtite is a hydrated carbonate of magnesium, chromium and iron, which occurs in massive aggregates of platy micaceous crystals. Its colour is an attractive lilac or rose-pink, and it has been occasionally cut in cabochon form, but it is extremely soft, with a hardness of only about 1½ on Mohs's scale. The average refractive index is about 1·53, specific gravity 2·15 to 2·22. Being a carbonate it is soluble in acid with effervescence. It occurs as an alteration product in serpentine. It (or a closely allied mineral) has been described from Tasmania (it is named after R. Sticht of Tasmania), the Transvaal, Morocco, Quebec and the Shetland Isles.

THOMSONITE

Thomsonite is a member of the zeolite family of minerals, and was named after T. Thomson. It is a hydrated calcium-sodium alumino-silicate, and crystallizes in the orthorhombic system. When pure it is colourless and of no interest as ornamental material. Like chlorastrolite (p. 443), however, it is found weathered out from lavas in the Lake Superior district as rounded aggregates irregularly mottled or banded in various colours, red, yellow, brown and more rarely green (lintonite). The average refractive index is about 1·52, much less than that of chlorastrolite. The hardness is 5 to $5\frac{1}{2}$, specific gravity 2·3 to 2·4. The only noteworthy localities are in the Lake Superior district; material somewhat similar to lintonite has been found at Allival, Rum.

VARISCITE

Variscite, so called from the ancient name, Variscia, for the district in Saxony where it was first known, is a hydrous aluminium phosphate, corresponding to the formula $AlPO_4 . 2H_2O$, which may achieve shades of green owing to the chromium and iron that may replace some of the aluminium. The crystals have biaxial negative birefringence, the values of the least and the greatest of the principal refractive indices varying from 1·55 and 1·58 to 1·56 and 1·59 according to the relative amount of iron present. The lustre is vitreous. The specific gravity varies from 2·52 to 2·60, and the hardness corresponds to the symbol 5 on Mohs's scale.

Variscite suddenly came into the ranks of ornamental stones by the discovery of green, nodular masses, resembling turquoise, in various parts of Utah in the United States. These were called utahlite after the State in which they were found; not a happy choice, because there was already known a mineral called utahite, of very different characters, being a hydrous iron sulphate. The term amatrix, which is a contraction of American matrix, has been given to concretions of variscite in quartz or chalcedony; owing to the contrasting tint of the green centre with the grey, reddish or brownish surround, they form very attractive pieces. The hardness, owing to the presence of silica, runs a little higher than for variscite, namely, from 5 to 6 on Mohs's scale.

VIOLANE

A massive, violet-blue pyroxene, to which on account of its colour the name violane has been given, is near diopside (p. 398) in chemical composition. Its refractivity is about 1·69, specific gravity 3·23, hardness 6 on Mohs's scale and lustre waxy. It makes a handsome stone when polished.

WARDITE

Wardite, so named after H. A. Ward, is a hydrous aluminium phosphate with the formula $Na_4CaAl_{12}(PO_4)_8(OH)_{18} . 6H_2O$, and occurs in pale-green granular layers near Fairfield, Utah. The crystals are probably tetragonal with a perfect basal cleavage. The hardness is about 5 on Mohs's scale, and specific gravity 2·81; the values of the ordinary and extraordinary refractive indices are 1·590 and 1·599 respectively, the double refraction being uniaxial in character and positive in sign.

ZOISITE (THULITE)

Another handsome ornamental stone is the rose-pink variety of zoisite known as thulite. In chemical composition it is a calcium–aluminium silicate, corresponding to the formula $Ca_2Al_2(AlOH)(SiO_4)_3$. Zoisite and thulite were named after Baron von Zois and Thule, the old name for Norway. Zoisite is orthorhombic and has positive biaxial birefringence, whereas the related epidote (p. 402) is monoclinic and its biaxial birefringence is negative; both minerals possess one direction of perfect cleavage. The former has lower refractivity, the values of the least and greatest of the principal refractive indices being 1·700 and 1·706; the double refraction increases with the substitution of iron for some of the aluminium. Thulite is markedly dichroic, the three principal colours being light rose, deep rose and yellow. Its lustre is vitreous. Its specific gravity is 3·12, and hardness 6 to 6½ on Mohs's scale. The finest specimens have come from the district of Telemark in Southern Norway, and so the stone gained its name. A green zoisite rock from Tanganyika, which encloses crystals of corundum, has been called 'anyolite'.

Section D. Organic Products

Of the substances discussed in this section none can lay valid claim to rank as a gemstone in the strict meaning of the term; they may perhaps be accepted as gems in the sense of beautiful objects, but clearly not as stones, for the indisputable reason that they owe their formation to the action of living matter. It would, however, be sheer pedantry to exclude on that account pearl, which from the earliest times has always filled one of the highest positions in the ranks of jewels. Thus Pliny [1] tells us in one passage of his great work that pearls ranked at the very top and in another passage that they came next to adamas (p. 257) and above emerald. Coral, amber and jet naturally follow in the wake of pearl, inasmuch as they are or have been frequently used in jewellery. Ivory and tortoise-shell are admittedly in a different category, because they provide material for ornaments.

From the scientific aspect the inclusion of ivory is justifiable, because of its close analogy to pearl; both are secreted by living organisms and both consist of an intimate mixture of mineral and organic matter, though in both respects the actual constituents are different. Coral is outstanding in the group, because it is composed almost entirely of a single mineral species. Jet, on the other hand, has originated from vegetation and contains no mineral matter; it, however, differs in character from amber and the natural resins generally, which have likewise originated from vegetation. From the point of view of jewellery amber is the most conspicuous of the natural resins. Tortoise-shell is wholly composed of organic material, and its inclusion in the section may be justified only by the fact that it is a companion of ivory and used for similar purposes.

It is a necessary consequence of the introduction of ivory into the section that it becomes desirable to include a description of the artificial substance, namely celluloid or xylonite, that has for many years past

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[1] 'The first rank, then, and the very highest position among all valuables, belongs to the pearl.' (Principium ergo culmenque omnium rerum pretii, margaritae tenent.) Loc. cit., book 9, ch. 35. 'Next (after diamonds) in esteem with us are the pearls of India and Arabia.' (Proximum apud nos Indicis Arabicisque margaritis pretium est.) Loc. cit., book 37, ch. 4.

been substituted for it for a variety of purposes. This substance is a synthetic resin. One of the noticeable features of recent years has been the extensive development of such substances, now known as plastics. Some of them are transparent, and both colourless and coloured, and are therefore admirably adapted to decorative purposes; the discussion has consequently been widened so as to cover other synthetic resins.

XXXIX

PEARL

A. NATIVE PEARL

From that unrecorded day, when some scantily clothed savage, seeking for succulent food, opened an oyster and found to his astonishment within its shell a delicate silvery pellet that shimmered in the light of a tropical sun, down to the present age without any intermission, the pearl has held a place all its own in the ranks of jewels. Though it be lacking in durability, its beauty cannot be disputed, and large examples are sufficiently uncommon to tax the deepest purse. Despite the competition of the cultivated pearl and the mass of obvious imitations that is nowadays abroad, the native pearl is esteemed as highly as ever. The word, pearl, is adapted from the French *perle*, which itself came from the late Latin *perla*, but the ultimate origin of the last word is uncertain; it may be derived from *perula* the diminutive of *pera*, used by the common folk for *pirum* (pear), from *perna*, in Greek *πέρνα* (ham), referring to a bivalve, or from pipula (globule). Pliny used the word *unio* for single pearls of high quality, and *margarita*, from the Greek *μαργαρίτης* (pearl), for the smaller ones of less interest.

The faculty of secreting a calcareous substance is widespread in the animal kingdom. The phosphate is the principal constituent of bones and teeth, while the carbonate supplies much of the material of egg-shells containing embryos, and of shells forming the habitations of molluscs. It is this faculty, when exercised by certain species of molluscs, that in certain abnormal circumstances results in those lovely shimmering pellets known as pearl.

The finest pearls are produced by certain species of bivalve molluscs, in which, as the name signifies, there is a pair of shells, slightly hollow on the inner side and hinged along one edge, within which the animal lives. The mollusc is simple in organization and consists of a visceral mass, which lacks a head, and in which the gills serve for nutrition as well as respiration, together with a foot, a bundle of horny fibres (the byssus) which is protruded from the shell and anchors it to stones or coral on the sea-bottom, and the mantle, which is the animal's most

1. Inserting the pellet

2. Removing the pearl

XXV. CULTURED PEARLS

(*Reproduced by courtesy of K. Mikimoto*)

1. Rafts bearing oyster-cages

2. Girl divers

XXVI. CULTURED PEARLS

(Reproduced by courtesy of K. Mikimoto)

remarkable feature. This mantle is in the form of two lobes or flaps which envelope the mass and have on their surfaces epithelium cells with secretive powers. The material exuded by the cells depends upon their position in the flaps. At the edge of the outer surface of each flap the cells secrete the organic substance known as conchiolin, a scleroprotein, which is brown to black in colour. Passing away from the edge along the outer surface, we come to a zone of cells which secrete calcium carbonate in the form of prisms of either calcite or aragonite; the pearl-oyster favours the former and the pearl-mussel the latter. Passing on further, we finally reach the zone of cells which secrete calcium carbonate, but in the form of flakes which make up the irridescent substance known as nacre or mother-of-pearl. The shell on each side is therefore built up in three stages, which are in continuous and simultaneous operation during growth. As the mantle expands, a sufficient thickness of conchiolin is formed, the second zone of cells deposit on the inner side of the conchiolin layer a layer of prisms of calcium carbonate, and finally the third zone coats this with a nacreous lining. It should be noted that the cells of both the second and third zones exude also small quantities of conchiolin, which acts as cementing material. When repairs become necessary to the shell all the epithelial cells appear to be capable of secreting the three types of deposit in the correct sequence. The two shells can turn about a hinge, generally articulated with teeth, near the edge remote from the opening. The two valves of the shell are connected by a strong muscle; when the muscle relaxes, the valves open and the animal within is exposed. The food, in the shape of plant remains, protozoa, etc., is wafted with the respiratory water by cilia into the gills.

Although it is possible for any mollusc of either the bivalve or the univalve kind, which possesses a shell with a nacreous lining, to produce a pearl, few of them do—even the tiniest pearls are seldom, indeed, found in the edible oyster—and only two groups of shells, the pearl-oysters (*Pinctada* [1]) and the pearl-mussels, repay the cost of systematic fishing.

Pearl fisheries have been known since very early times on the Arabian coast of the Persian Gulf and in the Gulf of Manaar off the north-west coast of Ceylon. These famous fisheries are important to-day, and a large proportion of the pearls that come into the market have been fished in the Persian Gulf. In ancient times many pearls came from the Red

[1] Generic names which were in use for the pearl-oysters before *Pinctada* was adopted in accordance with the requirements of the International Rules of Zoological Nomenclature were *Margaritifera* and *Meleagrina*. *Margaritifera* belongs properly to a genus of pearl-mussels, a species of which is cited on p. 467.

Sea, but to-day few are found there. In modern times an important fishery, particularly for mother-of-pearl, has existed on the north to north-west coast of Australia. Other areas where fisheries exist are the Mergui Archipelago off the coast of southern Burma, the Sulu Sea, Tahiti and other Pacific islands, the coast of New Guinea and Borneo, the Gulf of Mexico, the coasts of Venezuela, where pearls were found by Columbus, the Gulf of California and the west coast of South America. Pearls are also found off the coasts of Japan, but are now neglected in favour of the cultured pearl. River-pearls were gathered by the Romans in Great Britain, and one from the river Conway is said to be in the British regalia. In olden times Irish pearls from the mountain streams were highly prized in Europe. At the present time river pearls are systematically fished only in rivers in Bavaria and in North America.

The species of pearl-oyster which excels all others as a producer of pearls is the one known as *Pinctada vulgaris*, which flourishes in the Persian Gulf and the Gulf of Manaar. It is found also round Malaya and off the coasts of Australia and New Guinea, but is not the chief pearl-oyster in these waters. In size this species is comparatively small, the shell being about 2½ inches (6 cm.) in diameter, though it is slightly larger in the Persian Gulf. The Persian variety is somewhat darker than the Ceylon one, and its shell is distinctly reddish as compared with the pink tint of the latter. Much shell under the name of Lingah shell is exported from the Persian Gulf. This species is noted for the beautiful silvery-white colour, regular shape and lovely lustre of its pearls, which therefore command high prices in relation to their size. The pearls are not large, rarely exceeding 12 grains in weight, and are mostly of moderate size or are the small ones known as seed-pearls. This species is fished almost entirely for the pearls that it produces, its shell being comparatively unimportant.

Ranking next to the above species as a pearl producer and surpassing it as a supplier of mother-of-pearl is the pearl-oyster called *Pinctada margaritifera*. It is the principal pearl-oyster on the north coast of Australia. Much larger in size, measuring up to 8 inches (20 cm.) in diameter, it is mainly of value for its shell and only incidentally for its pearls. The species is widely distributed, but in many areas perceptible differences have developed which have led to the recognition of varieties. One of these is the black-lip shell of Australia, which is somewhat black on the lip of the shell. Another smaller variety occurs in the Persian Gulf; it is, however, much larger than the Lingah shell and is fished for its mother-of-pearl, which is known as Bombay shell, because at one time it was marted from there. The nacre is slightly rosy in tint with a greenish-yellow margin, and the pearls are yellower in tint and larger in size than those produced by the principal pearl-oyster of these waters. A somewhat similar variety in the Red Sea has a darker nacre, but its mother-of-pearl is called Egyptian shell or Alexandria shell, because before the opening of the Suez Canal it was marted at Alexandria.

Another variety, with a green nacre and nearly as large as the Australian pearl-oyster, is scattered round the islands of the southern Pacific Ocean; it supplies the black-edged shell, and the Tahiti, Gambia or Auckland shell according to the exporting centre. Lastly, the Panama shell is supplied by a variety with a green-edged nacre, which flourishes in the Gulf of California; it is noted for the black pearls that it produces.

The largest species of pearl-oyster is *Pinctada maxima*, which lives off the north and west coasts of Australia and round Malaya. The shell measures up to about 12 inches (30 cm.) in diameter, and the pair weigh up to 12 lb. (5·5 kg.). This species provides some of the largest pearls, but its commercial interest is mainly in the mother-of-pearl, which is called Sydney or Queensland, Port Darwin, West Australia, New Guinea, Manila, Macassar or Mergui shell according to the marting centre. Slight differences of tint characterize the nacre from the various areas; thus from Australia it is almost uniformly silver-white, from Macassar it is similar but more iridescent, and from Manila it possesses a wide golden border.

Yellow pearls are yielded by a small species (*Pinctada carchiarium*) living in Sharks Bay on the coast of Western Australia. The shell, which is about 3 inches (8 cm.) in diameter, has a yellowish-green nacre with a pale-yellow margin. Other small species are *Pinctada radiata*, fished mostly round Margarita Island off the Venezuela coast, and *Pinctada martensi*, which lives around the islands off the coast of south Japan. The importance of fishing for native pearls in Japanese waters is, however, obscured by the cultured-pearl industry, since it is difficult to market the former separately.

The pearl-mussels, which inhabit inland waters, belong to the family Unionidae. The most important species in Europe is *Margaritifera margaritifera*, which historically is of interest as a pearl producer and still is to some extent fished for its shell as material for buttons. From the writings of Suetonius, Tacitus and Pliny it appears that[1] the

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[1] 'It is a well-ascertained fact that in Britannia pearls are found, though small, and of bad colour; for the deified Julius Caesar wished it to be distinctly understood, that the breast-plate which he dedicated to Venus Genetrix, in her temple, was made of British pearls.' (In Britannia parvos atque decolores nasci certum est: quoniam Divus Julius thoracem, quem Veneri Genitrici in Templo ejus dicavit. ex Britannicis margaritis factum voluerit intelligi.) Loc. cit., book 9, ch. 35.

river pearls of Britain were known and valued by the Romans. River pearls from mountain streams in Ireland also were long held in repute.

Several species of pearl-mussel are fished in the United States for their shell, which is used for the manufacture of pearl buttons. The most important of them is the niggerhead (*Quadrula ebena*), the shell of which reaches a diameter of 4 inches (10 cm.) and a weight in pairs of 4 oz. (100 grams). Many thousand tons of this pearl-mussel have been fished from the Mississippi Valley, principally for the button industry, although valuable pearls have been found. A somewhat similar species is the bullhead (*Pleurobema aesopus*), but its nacre is not so iridescent nor are its pearls of such good quality. The best species for pearls are the blue-point or three-ridge (*Quadrula undulata*), and another also known as three-ridge (*Quadrula plicata*), though the shell of neither species is so useful. The sand-shells (*Lampsilis*), which are elongated in shape with an extreme length of 6 inches (15 cm.) and rather flat, lend themselves admirably to button manufacture and are in great demand for that purpose. Another species of similar shape, the buckhorn (*Tritogonia verrucosa*), with beautiful iridescent nacre is likewise in great demand. The butterfly mussel (*Plagiola securis*) has a shell with an unusually permanent lustre and produces beautiful pearls.

The pearl-oysters are believed to live from three to eleven years, if undisturbed. The pearl-mussels appear to be longer lived, and to reach fifty or even a hundred years, if nothing untoward happens to them. In both instances propagation takes place twice a year by means of eggs, from which emerge larvae.

Other pearl-producing molluscs which may be mentioned are the sea-mussels (Mytilidae), the wing-shell (Pinna) and the giant clam (*Tridacna gigas*). The last named provides the largest and heaviest shells known, reaching as they do to 3 or 4 feet (about 1 m.) in diameter and in pairs to 500 lb. (225 kg.) in weight.

Mention should be made of the great conch (*Strombus gigas*), one of the largest of the univalve molluscs, the shell of which may measure up to 12 inches (30 cm.) in diameter and 6 lb. (3 kg.) in weight. The shells are highly valued because of their lovely pink colour and graceful shapes, and the pearls, also a lovely pink, are only an incidental discovery. The great conch abounds round the West Indies, especially the Bahamas, and off the coast of Florida.

Pearls are also yielded by the abalones or ear-shells (Haliotidae), which suggest the human ear in shape. The quality of the nacre surpasses that of many pearl-oysters. The pearls, though generally small, are of considerable interest because of the unusual colours that they display. The commonest tint is green, but yellow and even blue colours are found.

The production of a pearl by a mollusc is an abnormal process. If free from disease or hostile attack, no oyster or mussel will supply a pearl, and the presence of pearls is often indicated by the distorted shape of the shell, a clue that guides the pearl-divers in their search. Only about one in forty pearl-oysters contains a pearl, and the number of pearls in each is usually one or at most three, though as many as eighty-seven have been said to have been found in an Indian and sixty-seven in a Ceylon shell. The more numerous the pearls in a shell the smaller the size, and larger ones are always alone. The comparative rarity of pearls and the still greater scarcity of pearls of high quality explain why pearl-fishing is such a gamble. The methods in general use to-day for gathering the shells from the sea-bottom are much the same as they have been for two thousand years past, and all that the divers have to help them are clips to close the nostrils, stalls to protect the thumbs and fingers, goggles to aid the sight under water, ropes for hauling them up to the surface, and, in case of descent feet foremost, stones, each weighing about 40 lb. (18 kg.) to carry them quickly down. Even so they can work down to depths of 30 feet (9 m.), and remain under water for as long as a minute and a half, though the normal duration does not exceed a minute. In the Australian waters, however, modern diving-suits are used. No attempt is made to determine beforehand whether pearls are present, and, since relatively so few shells contain any, there is great wastage. Usually the animals are allowed to die so that the shells can be readily opened, and pearl-fishing is consequently accompanied by an unpleasant stench.

The process of formation of a pearl is similar to that of the shell. It is built up from the inside outwards, layer upon layer, by secretions from the epithelial cell tissue. In the true gem pearl these layers are composed of nacre, the prismatic layer of shell formation being rarely encountered except in some freshwater pearls. Sometimes oriental pearls have a small core that is darkened by excess of organic matter. It was formerly supposed that the actuating cause of a pearl was solid material, such as a grain of sand, or a living animal, such as a parasitic worm, which had intruded within the shell, and the limbless animal in default of other means could immobilize the intruder only by sealing it up. Such no doubt was the initial cause, but the immediate cause was the irritation that had been set up, and pearls may contain no foreign nucleus at all. The iridescent lustre of the surface of a pearl and of the nacreous lining of the shell is peculiar and characteristic, and is known as orient; it is the combined effect of two optical phenomena: the interference of light from the succession of thin translucent laminae forming the surface, and the diffraction of light reflected from the grating composed of the closely packed lines in which these laminae meet the surface. The latter effect is less constant than the former, because it varies with the arrangement of the laminae. Sometimes the laminae, rounded in section, are superimposed on one another at numerous spots in close juxtaposition, diminishing in size towards the surface; the markings in such case are approximately circular instead of linear. Pearls are usually more iridescent than the mother-of-pearl lining of the corresponding shells, because owing to the curvature of their surfaces the lines representing the edges of the laminae are closer together. The translucency of the surface layers varies in degree, and in regard to the quality of the lustre jewellers speak of the water of pearls just as in the case of diamonds. Sometimes the outer skin is so rich in conchiolin that the colour is brown; such pearls are devoid of lustre and consequently valueless. Pearls which display fine orient are sometimes described as ripe, while those of poor quality are said to be unripe.

The colour of pearls is conditioned by the translucency of the outer skin and by the character of the underlying layers which show through it. Calcium carbonate, whether in the form of calcite or in that of aragonite, is colourless or white, whereas conchiolin is yellowish in thin sections, the colour deepening to brown and nearly black. Some of the faint tints that occur are no doubt due to small quantities of other matter present in the water absorbed. The colour is therefore ordinarily white or faintly tinged with yellow, and less frequently reddish, salmon-pink or blackish-grey. The white pearls are often distinctly greenish in tint when first extracted, and become white as they dry and lose the water that they contained. The so-called blue-pearl, which is really a lead-grey in tint, owes its effect to the superimposition of a thin crust upon a dark kernel rich in conchiolin. The cause of the colour of black pearls is not clear, but appears to be bound up with the nature of the water in certain areas, for instance the Gulf of Mexico, La Paz (Mexico) and certain of the Pacific Islands. The tint of pearls which is preferred varies in different parts of the world and conforms to the hue of the skin of the wearer; it also depends upon the intensity of the sunlight at the particular place. White pearls appear best on a white skin, and yellowish or darker pearls are better with a darker skin.

On the whole the products of the various waters are sufficiently consistent in colour and appearance to enable an expert to recognize with confidence the origin of any pearls that come before him. Thus the colour of pearls from the Persian Gulf is a delicate creamy tint, from Ceylon similar but rather paler, from Australia white or silvery white, from the West Indies bright rose-red with wavy white lines, from Panama golden-brown, from Mexico reddish-brown and black, and from Japan white, often with a greenish tinge. The so-called India pearls, which are mostly fished off the coast of Ceylon and are merely marketed at Madras, have a faint rosy tint. Under the influence of ultra-violet rays practically all the pearls used in commerce display a sky-blue fluorescence of varying intensity.

Although pearls contain a high percentage of mineral matter, it is in a compact form composed of numerous tiny crystals, and consequently, not being like a single crystal subject to the inexorable laws of interatomic action, they may assume almost any shape from the perfect sphere to the most fantastic form. The shape depends upon the position within the shell where the pearl developed. If the intruding object has penetrated between the mantle and the shell, it becomes coated with nacre which adheres to the shell, and the result is a blister-pearl. The intrusion may be by the gap between the shells or by boring through the shell, and may be caused by non-living substances, such as grains of sand or even broken bits of the shell, or living creatures, such as parasitic worms or sponges. If the intrusion is through the shell, a very large blister may be built up, which on fracture sometimes contains a round pearl. The most perfect pearls are formed within the tissues of the animal itself. Whatever may be the cause of the irritation, it results in the formation of a concave dent in the outer surface of the mantle. The dent deepens and develops until it becomes closed and assumes the shape of a hollow sphere lined with epithelium cells. The cells of the outer surface of the mantle coalesce, and the hole made by the dent is obliterated, with the result that the hollow sphere or pearl-sac, as it is termed, is pressed into the underlying tissues; such pearls are often called cyst-pearls. The annual deposit of nacreous material is nearly constant after the first year; according to A. E. Alexander,[1] on the assumption that the rings visible in thin sections represent seasonal growths as they do in trees, the rate during the first year is 2·30 mm. (0·09 inch), falls abruptly to 0·38 mm. (0·015 inch) during the next year, and scarcely varies thereafter. If the pearl-sac is somehow interfered with or its position is too near the edge of the mantle or is otherwise unfavourable, or, if the object that is being sealed up is not regular in shape, the result is an irregular pearl.

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[1] *Science*, 1941, vol. 93, pp. 110–11.

Pearls from the Persian Gulf are commonly called orient or oriental pearls. Many names have been introduced to distinguish pearls of different kinds, the terms in most general use being round, baroque, blister, button, drop and seed. Round pearls are apparently perfect spheres in shape; they command the highest prices. If of exceptional size, they are sometimes known as paragons or monster-pearls. Baroque, or barrok pearls are irregular in shape. Blister, wart or chicot pearls are swellings in the nacreous lining of the shell. They often contain extraneous matter such as water or mud, and, if very large, may have a round pearl within them. Button, or bouton, pearls have rounded tops and flat bases. Drops, or pear-eyes are pear-shaped pearls; they lend themselves excellently for use in pendants or ear-rings, and therefore command good prices. Seed-pearls are small, round pearls which are less than a quarter of a grain in weight. The term dust-pearls is used for tiny ones too small for use.

Among the many other kinds of pearls, to which special names have been given, mention may be made of the following: egg-shaped pearls, which are either oval in shape or rounded at both ends; hammer-pearls, which are shaped like the head of a hammer; and hinge-pearls, which are narrow and doubly pointed, and are so named because they occur near the hinge part of the shell. Pearls that come from molluscs other than pearl-oysters or pearl-mussels are known by the name of the mollusc in which they originated; thus conch-pearls from the univalves, either the common conch (*Strombus gigas*) or the large conch (*Cassis cornuta*); abalone-pearls from the abalones or ear-shells (Haliotidae); and clam-pearls from the clams, for instance the quahog or hard clam (*Venus mercenaria*) of the Atlantic coast of the United States, or the giant clam (*Tridacna gigas*) of tropical seas. Conch-pearls are alternatively called pink pearls. The so-called *coque de perle* is an oval section of the rounded whorl of the shell of the Indian nautilus; because of its thinness it has to be backed with cement, and in appearance it resembles blister-pearl.

Very occasionally two or more pearls are found adhering together, the most notable example of this phenomenon being the Great Southern Cross (p. 476).

Large pearls are sold separately, but small ones come into the market, bored and strung on silk in bunches. The unit of weight used is the pearl-grain, which is a quarter of a carat. The base method of calculating the value of pearls, which depends upon the square of the weight in grains, has been explained in a previous chapter (p. 147). The base or unit varies from 6*d*. to 100*s*. according to the shape and quality. Perfectly round pearls command the best prices, next pear-drops, and lastly buttons; but, whatever be the shape, the pearl must have orient, without which it is valueless. Seed-pearls are sold by the carat.

For use in necklaces and pendants pearls are drilled with a steel drill, an easy operation on account of their softness, and are threaded with silk; if for use in ear-rings or as the centre drop of a pendant, they would be partially drilled. Pearls harmonize well with diamonds, and small ones make a successful frame for coloured stones. Pearls, to be set in rings or generally in positions where the upper half alone would show, are generally sawn into halves; button-pearls are serviceable for this purpose, since they are already suitably shaped.

The chemical composition of pearl is obviously dependent upon the relative amount of mineral matter (calcium carbonate), the organic matter (conchiolin) and water, of which it consists. Not many data are available. On the average, pearls appear to be composed approximately of 86 per cent calcium carbonate, 12 per cent conchiolin and 2 per cent water. Some of the less common pearls, such as, for instance, those from the wing-shell (Pinna) have percentage amount of water running up to 23 with corresponding reduction in that of calcium carbonate.

If a round pearl be sliced through its centre and the section be examined with a strong lens or a microscope, it will be seen that its structure consists of a series of more or less continuous concentric shells, which, however, differ in character according to the nature of the cells that secreted them, and resembles that of an onion.

If the section be placed upon a refractometer and the shadow-edges examined, the one corresponding to the greatest of the refractive indices may usually be observed. The minute crystals of carbonate of lime composing the structure are normal to the concentric shells, and therefore radiate from the centre. As will be seen from the discussion of the specific gravity below, the calcium carbonate crystallizes normally in the form of aragonite. Although its crystals are orthorhombic and biaxial, they are very nearly hexagonal and uniaxial, the values of the principal refractive indices being 1·530, 1·682 and 1·686 respectively. The greatest of them corresponds therefore very nearly to the ordinary refractive index of a uniaxial crystal; consequently the shadow-edge corresponding to it will always be visible whatever be the position of the prismatic crystal on the refractometer, but the other shadow-edge may have any position between this and that corresponding to the least of the principal refractive indices, the result being a blur with an ill-defined lower limit. The effect would be similar if the crystals were calcite, since its ordinary refractive index, 1·658, is also the highest; in this case, however, the shadow-edge would correspond to a distinctly lower value.

Because of their composite and variable nature, the specific gravity of pearls has a considerable range. Pearls from the Persian Gulf have a normal value of 2·715, and 98 per cent of the values lie between 2·68 and 2·74. For Australian pearls the normal value is 2·74 and the range 2·68 to 2·78. The Venezuelan pearls, which are remarkable for their superior translucency, as revealed especially when examined by the endoscope, have a slightly lower normal value, namely 2·70, than those from the Persian Gulf, the range being 2·65 to 2·75. The Japanese natural pearls are remarkable for the great variation of specific gravity that characterizes them; the normal value lies between 2·70 and 2·74, and the range extends from below 2·66 to 2·76. Freshwater pearls from the rivers in North America exhibit an even wider range, extending from below 2·66 to over 2·78, and a perceptibly lower normal value, it being about 2·66 to 2·70. The probable values of the specific gravity of native pearls from the fisheries mentioned above and of cultured pearls are shown graphically in fig. 138.

The specific gravity of aragonite is 2·94 and that of calcite is 2·71. The latter figure being close to the normal value for pearls, it is clear that if appreciable amounts of conchiolin (specific gravity 1·34) and of water (specific gravity 1·0) are present much of the calcium carbonate must be in the form of aragonite. A pearl with a composition near the average stated above could, indeed, have its carbonate content wholly in the form of aragonite, and X-ray powder photographs have been taken which support this. The composition of some pearls, however, showing only a few per cent of conchiolin and of water, is such as to suggest that a proportion of the carbonate must be present as calcite if the specific gravity is in the normal range. Further data correlating composition with specific gravity would be valuable.

The specific gravity of black pearls is lower than that of ordinary native pearls, ranging as it does from 2·61 to 2·69. Pink pearls or conch-pearls, which are devoid of the nacreous coating characteristic of the pearls previously mentioned, have a high specific gravity, about 2·85, which indicates a correspondingly higher proportion of aragonite in their composition.

The hardness of pearl is about the same as for aragonite, namely 3½ to 4 on Mohs's scale. Pearls therefore call for careful handling on account of their softness. They are, moreover, affected by acids and even by perspiration from the skin. It is unwise to wear pearl rings while the hands are washed, since the pearls may be dirtied, in which event it is almost impossible to restore their former appearance. It may be mentioned that acids attack the calcium carbonate and not the conchiolin; the oft-repeated story which Pliny[1] relates with such gusto, that Cleopatra, when entertaining Antony quaffed a draught worth a fortune by dissolving a pair of large pearls in vinegar cannot be literally true, because vinegar is too weak an acid to affect quickly calcium carbonate when protected by conchiolin; it is possible that she swallowed them whole, like pills, under the impression that they had dissolved.

Pearls are not cut like stones, and therefore as soon as the precious bloom has once gone, nothing can be done to revive it. Attempts have been made in the case of valuable pearls, to remove the dull skin on the chance of laying bare another iridescent layer beneath, but the operation is very delicate and not always successful. Even with the best of care, pearls must in course of time perish owing to the decay of the conchiolin constituent, and it is doubtful if any retain their appearance more than a century and a half. Pearls, which may be about two hundred years old, have turned black and appear like burnished steel so that they are almost unrecognizable for what they were. Attempts have been made to restore their appearance by means of ultra-violet rays, bleaching solutions, solvents, etc., but without success—a result only to be expected if the cause be the decay of the conchiolin. Pearls that have been discovered in ancient tombs crumbled to dust at a touch, and those formerly in ancient rings have vanished or only remain as a brown powder, while the garnets or other stones that were set with them are little the worse for the centuries that have passed by. Pearls in which the conchiolin has begun to decay with a consequential deterioration of the lustre are said to be sick. The deterioration can to some extent be stayed, and the translucency restored, by the immersion of the pearl in a solution of vinyl acetate or in oil, which fills up the incipient cracks responsible for the worsening of the lustre. Attempts have been made to improve the appearance of pearls by chemical means, but any success achieved is likely to be ephemeral, because the conchiolin will thereby be adversely affected.

The largest known pearl of modern times was at one time in the famous collection that belonged to the banker, Henry Philip Hope, and contained the blue diamond (p. 234). Nearly cylindrical in form, with a slight swelling at one end, it measures 2 inches (51 mm.) in length and 4½ inches (114 mm.) in circumference about the thicker, and 3¼ inches (83 mm.) about the thinner end, and weighs about 3 oz. or 1800 pearl-grains (450 carats). About three-quarters of it is white in colour with a

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[1] Loc. cit., book 9, ch. 35.

fine orient, and the remainder has a bronze tint. The Great Southern Cross consists of nine large pearls naturally united in the form of a cross, though it is believed that originally there were eight pearls and the ninth was added to complete the symmetry; it was discovered in a pearl-oyster fished in 1886 from the beds off the coast of Western Australia. La Pellegrina was the name of one of the most beautiful pearls known. Perfectly round and white in colour, it was said to have weighed 111½ pearl-grains. It was in the possession of Zosima Bros., of Moscow, at the beginning of last century. La Regente was the name of a large egg-shaped pearl, 337 grains in weight, that was formerly among the French Court Jewels. A fine set of pearls adorns the former Imperial regalia of Vienna, and the collection of jewels in the famous Green Vaults at Dresden contains many pearls of curious shapes. Splendid pearls are owned by the Shah of Persia. The Gaekwar of Baroda has a magnificent collection of pearls, including a carpet of pearls.

B. PEARL CULTIVATION

So long ago as the thirteenth century the Chinese had discovered the feasibility of coating foreign substances by introducing them within the shell of the freshwater pearl-mussel. They used a spatula to force the jaws of the shells slightly apart, and inserted by means of a bamboo stick the selected object between the mantle and the shell. The mussel was then returned to the water and allowed to live for some months or even two or three years. It was then found that the object had become coated with nacre and so fixed to the shell. The object might be a mud pellet or a bit of bone, wood or brass; very frequently small images of Buddha, cast in lead or stamped in tin, were treated in this manner. The art has been practised in China continuously for some seven centuries. About the middle of the eighteenth century the process was independently discovered by Linnaeus, the great Swedish naturalist, and some of the pearls which he succeeded in growing are treasured by the Linnean Society of London. He did not develop the process himself, but disposed of the secret of it in 1762. His method seems to have been to bore a small hole through the shell and insert a limestone pellet at the end of a fine silver wire to allow of its being moved so as to prevent its adherence to the shell. The process was not a commercial success and soon passed into oblivion.

Towards the end of last century the Japanese took up the art so long practised by the Chinese, and about 1890 had set up quite an industry. Their method was to cement small pellets of mother-of-pearl to the nacreous lining of the shell of the mollusc, which was then returned to the sea, and in this way to obtain something like blister-pearls. The rate of deposit of nacre per year is very variable, but appears to be perceptibly greater than in the case of undisturbed molluscs. The pellet was coated only on one side, and on removal from the shell had to be cemented to a piece of mother-of-pearl, which was ground to the usual symmetrical shape. These Japanese pearls, as they have since been termed, are therefore easily recognizable by examination of the back (plate XXIV).

Extensive experiments, which were carried on from 1914 onwards, chiefly by K. Mikimoto (1857–1954), led to an enormous improvement in the practice, and the resulting products are what are now known as cultured pearls. A shell is removed from one oyster, and an epithelium sac is cut out of the mantle. A mother-of-pearl bead is placed within the sac, which is closed with a ligature (plate XXV, 1). An incision is carefully made in the mantle of a second oyster, and the sac with its bead inserted in the underlying tissues. The oyster is then returned to the sea. The oyster deals with the introduced sac just as if it were formed of its own epithelium cells, and secretes nacre which gradually coats the imprisoned bead.

The process has now become a systematic industry (plate XXVI, 1). The spawn of the local pearl-oyster (*Pinctada martensi*) is collected, and the young oysters (spats) are placed in fine-meshed metal cages to protect them from star-fish, octopus and other enemies in the sea. Periodically the cages are cleaned and their contents inspected for disease, and after two years the oysters are removed to larger cages. The work is done by girl divers (plate XXVI, 2). The oysters attain to maturity in three years and are then ready for the operations to which reference is made above. The oysters containing the introduced mother-of-pearl pellets are placed in cages and returned to the sea, where they remain for a further seven years, provided that periodical inspection shows them to remain healthy. During that period on the average a thickness of 0·025 inch (0·625 mm.) of nacre is deposited on the pellet. Under very favourable conditions one quarter of the pellet-bearing oysters may yield a pearl; often the proportion is as low as a twentieth. Of the cultured pearls thus produced only a small percentage attains to a satisfactorily high-class standard.

The cages containing the pearl-oysters are suspended from floats which are joined together to form large rafts, as many as 80,000 cages going to a raft (plate XXVI, 1). Motor-boats are used to move the rafts from one position to another in the bay where they remain, so as to vary the food conditions. An immense number, about three millions, of pearl-oysters are operated upon each year, thus allowing good margin for losses.

Mother-of-pearl is selected as the material for the kernel, because it is easily worked into pellets and because the finished article can easily be bored. The size is carefully graded so as not to be larger than what the particular pearl-oyster can accommodate; if it exceeded a certain maximum size, the only effect would be to kill the oyster. Since the local species is comparatively small, the size is normally between ½ grain and 4 grains, and seldom reaches 6 grains and rarely indeed 12 grains. If, however, the larger species, *Pinctada margaritifera*, be used instead, cultured pearls up to 60 grains in weight are obtainable.

Whole cultured pearls first made their appearance on the London market early in 1921, and were alleged to be from a new pearl-fishery. As soon as the mother-of-pearl kernel was discovered, and their true nature consequently revealed, considerable consternation was caused among those concerned with the marketing of pearls. It was, however, soon found out that these cultured pearls displayed by fluorescence in the ultra-violet rays a peculiar greenish tint which markedly differed from the sky-blue effect of the native pearls from the usual fisheries. Later investigation showed that this difference in the fluorescent effect was related to the water in which the corresponding pearl-oyster lived, and was independent of the cause of the secretion of the nacre; it was therefore not an infallible test for discriminating the cultured pearl. It was, however, not long before other methods of testing, to which we shall pass, were devised, and there can now in skilled hands be no uncertainty whether a pearl has been formed without or with human interference. The result was that the price of the cultured pearl promptly fell to about half that of the native pearl, and later dropped to a fifth or even less. How far so great a disparity in value is justifiable is a moot point. As with all luxury articles, the price of pearls is regulated simply and solely by what willing purchasers are prepared to pay, and the connoisseur persists in holding the native pearl in far higher esteem than the cultured pearl. It might be argued that the view which he holds is absurd, because the nacreous coating of the two kinds of pearl is, so far as the eye can judge, the same; nevertheless, the fact remains that he infinitely prefers the native pearl. It is, moreover, open to question whether the cultured pearl with its nacreous coat of relatively limited thickness can really be regarded as on a level of excellence with the finest native pearl. It has been found by experience that the nacreous coat deposited round the mother-of-pearl bead may be rubbed through in course of time, if the coat be too thin and the cultured pearl be subjected to friction in course of wear, and further that owing to shrinkage the bead may even become detached from its coat and rattle inside its nacreous shell. Cultured pearls of good quality, however, are not prone to such mishaps.

The specific gravity of cultured pearls, in comparison with that of native pearls, is discussed below.

During the second world war the cultivation of pearls by the Japanese was brought practically to a standstill because of the diversion of labour to munitions and of the difficulties in obtaining materials and equipment; moreover, the increasing shortage of food led to the consumption of oysters which otherwise would have been used for the production of pearls. After the war shortage of equipment still remained a major problem, and revival of the industry was consequently slow. The extent of recovery, however, is indicated by the fact that in 1952 Japan exported cultured pearls to the approximate value of £1,750,000. Success has been achieved, at Lake Biwa, in the culture of freshwater pearls. Cultured pearls are also being produced in Brecknock Harbour, 200 miles north-east of Broome, W. Australia.

C. DISCRIMINATION OF CULTURED PEARLS

In order to ascertain with certainty whether a particular pearl is of the cultured or the native kind, it is necessary to determine whether or no the kernel, if present, is a mother-of-pearl bead. For this purpose the most reliable methods are those depending upon observations made with an instrument called the endoscope [1] or upon the use of X-rays. Observations made with a microscope or a lens are helpful, but cannot be regarded as wholly trustworthy.

The endoscope (plate XXVII) is applicable to drilled pearls only. Its essential feature is the hollow needles supplied with the instrument, which are of three different diameters: 0·3, 0·4 and 0·5 mm. (0·012, 0·016, 0·020 inch): that needle is selected which fits, though not too tightly, the bore of the pearl to be tested, so that no stray light escapes between it and the cylindrical wall of the bore. A condensing lens concentrates the rays from a strong source of light, usually an electric arc-light, into a small tube, on to which the needle, with the pearl already threaded upon it and mounted in its holder, is fitted for each test. The needle itself remains fixed in position during the test, but the pearl is movable to and fro along it by means of a vice which grips it lightly and is actuated by an arm below.

The rays of light falling upon the nearer mirror are thrown perpendicularly upon the wall of the bore (fig. 136). Since the structure of a

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[1] Endoscope is derived from two Greek words ἔνδον (within) and σκοπεῖν (look).

native pearl consists of a series of minutely thin concentric shells, the light thus thrown upon the wall will tend to follow the curvature of the shells and return to the wall, and, if the further mirror be situated so that the centre of the several spherical shells of the pearl is midway between the two mirrors, the light will be reflected into the microscope and so to the eye. In practice the pearl is moved backwards and forwards along the needle, and it is immediately seen whether a flash of light appears; in fact, the observation is of the simplest description. If, on the contrary, the pearl be a cultured one and have a mother-of-pearl kernel, the layers are nearly flat and not curved and no longer return to the wall of the bore; in this case, instead of a flash a dull grey colour, which remains the same as the pearl is moved on the needle, appears in the microscope, and a streak of light is visible where the light emerges through the surface of the pearl. The method is easy and rapid, and in skilled hands pearls can be tested at the rate of two hundred per hour.

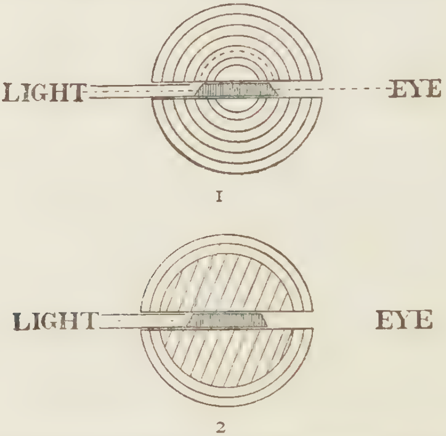
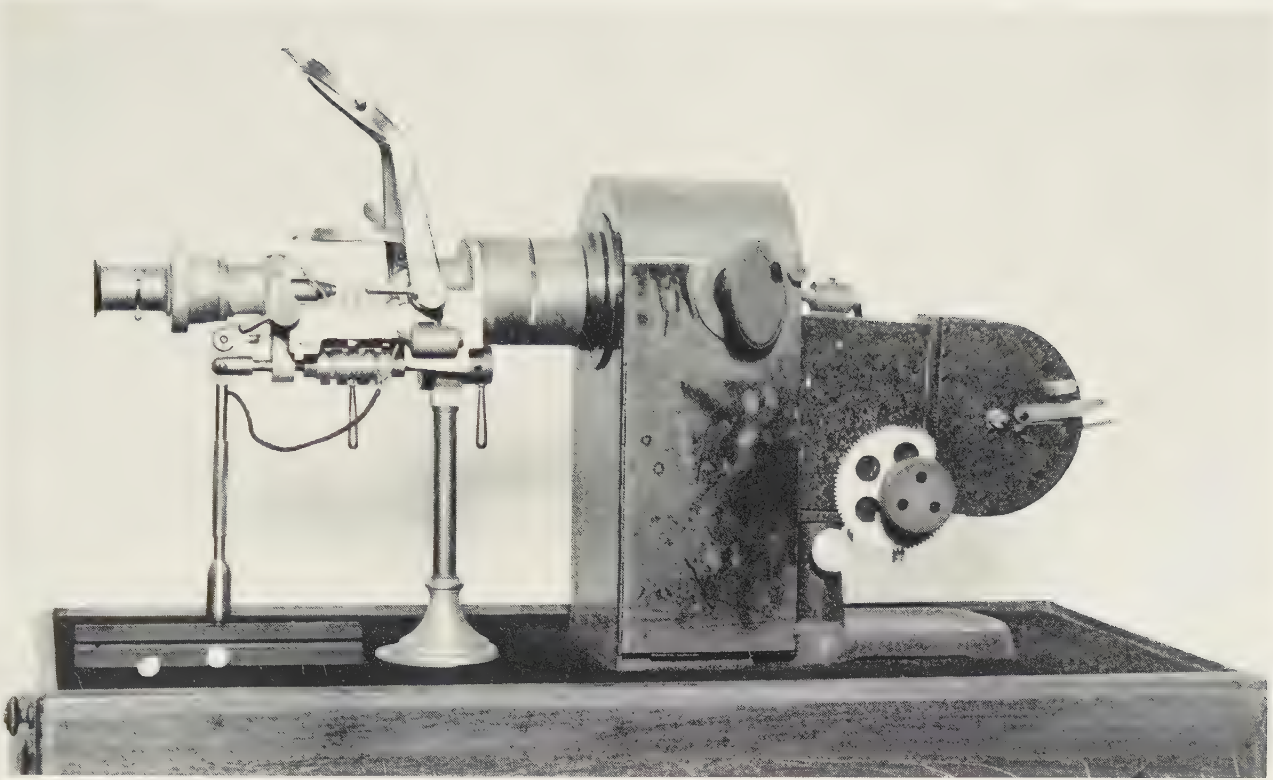


FIG. 136.—Endoscope needle in: (1) native pearl, (2) cultured pearl.

With the aid of the mirror nearer to it the microscope may be focused on to the wall of the bore, and the character of the wall studied from end to end by moving it along the needle by means of the vice by which it is held. The arm of the latter works in a vertical plane, and its end traverses a graduated scale, the pivot of the arm being so arranged that an interval of a centimetre on the scale corresponds to a millimetre on the wall. It is therefore, for instance, possible to measure accurately the crust surrounding the mother-of-pearl kernel of a cultured pearl.

There is also an arrangement of a mirror and a lens (plate XXVII) which enables the surface of the pearl to be studied. A native pearl



XXVII. Endoscope (*one-quarter actual size*)

possesses a characteristic appearance when illuminated from within by means of the mirror in the needle nearer the source of light. Means also are provided for illuminating the pearl when threading it on to the needle.

The principle upon which the use of X-ray apparatus is based is the fact that the structure of a native pearl consists of concentric shells nearly spherical in shape, whereas that of the mother-of-pearl kernel of a cultured pearl is formed of nearly flat layers. The pseudo-hexagonal axes of the minute calcium carbonate (aragonite) crystals are at right angles to the surface of the shells or of the layers (fig. 137). In the case therefore of a native pearl an infinite number of crystals radiate from the centre, and, if a narrow beam of X-rays be directed on to the surface of the pearl, practically the whole of it traverses the crystal multitude in the direction of the pseudo-hexagonal axis (fig. 137), and the resulting photograph is hexagonal in character. In the case of the cultured pearl a similar photograph will be given only if the beam be directed perpendicularly to the mother-of-pearl layers, and in directions at right angles to this the diagram will have nearly digonal (twofold) symmetry. X-ray photographs are shown on plate XXIV. This method is entirely independent of the drill-hole and can be applied to any pearl. In the case of necklaces the pearls need not be unstrung.

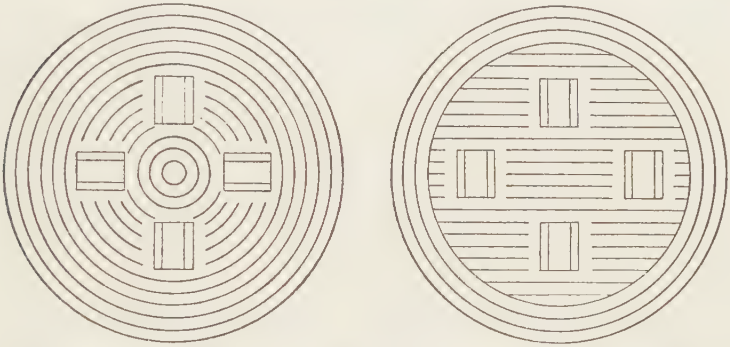


FIG. 137.—Arrangement of aragonite crystals in: (1) native pearl; (2) cultured pearl.

In recent years, X-radiography, using longer-wave ('softer') X-rays, has been developed as a most useful method of identification. Conchiolin has a low absorption for X-rays, which pass through it readily to produce darkening on a photographic negative. Interpretation of the observations requires care, but in general a natural pearl will show rings or segments of conchiolin throughout its structure whilst a cultured pearl will show only a single zone surrounding the mother-of-pearl nucleus.

It may be noted that under the influence of X-rays cultured are, as a rule, distinctly more fluorescent than native pearls, oriental pearls, indeed, being practically inert. The mother-of-pearl bead has a fairly strong fluorescence, which it imparts to the whole pearl, if the skin be not too thick to mask it. The phenomenon is much fainter than that due to ultra-violet rays, and must be viewed in complete darkness; on the other hand, it is far more discriminative.

A microscope or a lens may be used for the examination of a pearl illuminated by a powerful source of light, the pearl resting on a diaphragm of slightly smaller diameter than its own so that observations are not embarrassed by stray light that has escaped the pearl. By turning the pearl round it is feasible to be assured of the presence of the relatively large mother-of-pearl kernel; the easier transmission along the layers results in a glow on the surface in such circumstances, and even the striated nature of the mother-of-pearl structure may be visible. Owing to the highly reflective power of its spherical shells a native pearl always appears more or less uniformly dark when studied in this manner.

A special microscope has been devised for the study of pearls. The pearl under examination is placed in a hole in a metal plate, of smaller diameter than its own, and means are provided for illuminating it either from below or from above. The surface therefore can be studied and also the internal structure so far as it is transparent. An additional fitting is provided for the examination of the bore of a drilled pearl. Its upper part consists of a conically shaped piece, the apex of which is in the form of a small saucer that has a small hole in its centre. The pearl under examination is placed on the saucer with its bore vertical, and the piece carrying it is rotatable about a vertical axis, its scale being divided to 5°. Under the table bearing this conical piece is a circular piece working on a fine screw-thread, its scale being divided so as to give readings to 0·01 mm. Just as with the endoscope a spindle, as thin as a wire, passes up the drill-hole of the pearl. The best kind is made of rustless steel, which at its upper end is ground into the form of a plane mirror, inclined at 45° to the axis. The spindle is firmly attached to the under piece and is moved up and down within the bore by rotating the piece on its screw bearing. The pearl is illuminated from the side, and by means of the microscope the cylindrical wall of the bore may be studied; then, by means of the pointer attached to the screw-piece, the thickness of the kernel or of any layers may be measured

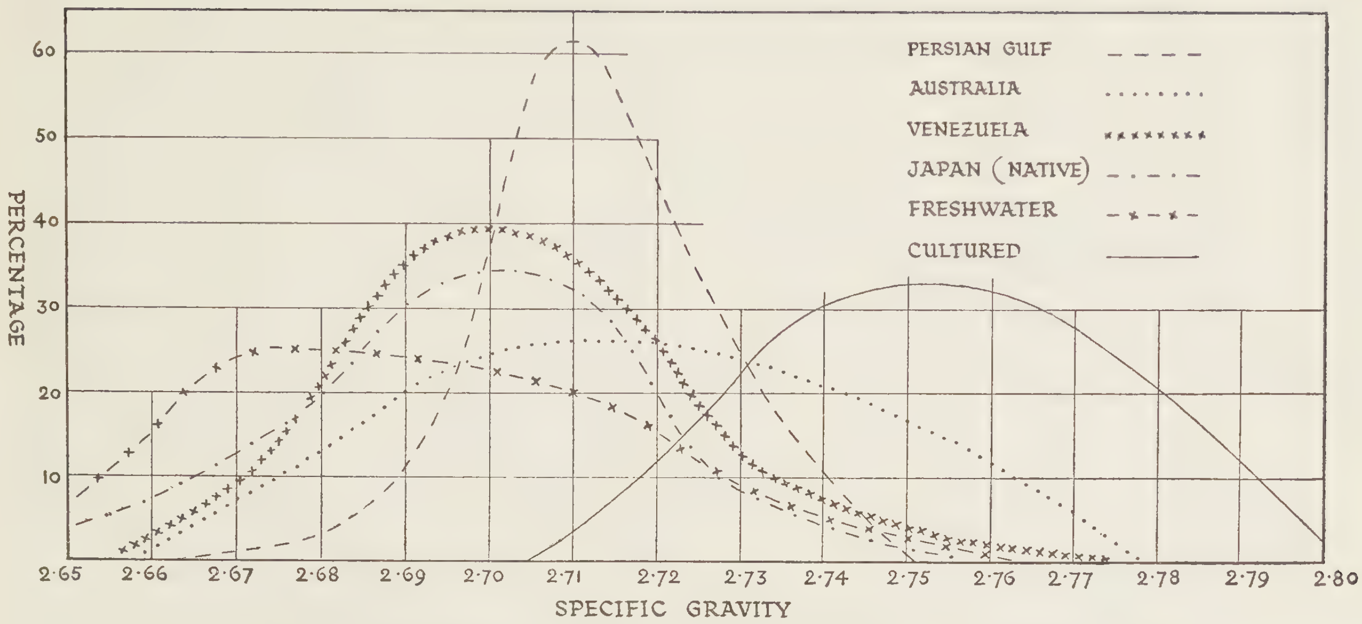


FIG. 138.—Graphs of specific gravity of native pearls from different waters and of cultured pearls.

or the position of any horizontal mark noted, and by means of the scale attached to the pearl-carrier the orientation of any spot may be noted.

Cultured pearls possess a relatively high specific gravity with a comparatively restricted range (fig. 138) due to the fact that they consist of a proportionately large bead surrounded by a thin skin. The mother-of-pearl of which the bead is composed has a specific gravity varying from 2·80 to 2·85, the average value being 2·82. It may be remarked that the Australian mother-of-pearl has a considerably lower value, namely, 2·74. The specific gravity of the outer skin ranges from 2·63 to 2·70, and is therefore lower than that of the kernel; if the skin be freed of its inner organic coating, the value exceeds 2·70. Since the bead accounts for at least 60 per cent of the weight of the pearl, and its specific gravity is high, that of the whole pearl is also high, the normal value being about 2·75 and the range extending from 2·72 to over 2·78; very occasionally, values below 2·72 may be met with because of the abnormal thickness of the skin. It will be noticed that in respect of the specific gravity cultured pearls surpass native pearls, and this fact may be conveniently used as a test for discriminating them. If, then, a liquid of density, 2·74,[1] be prepared, and a batch of pearls under examination be immersed in it, care being taken to expel by stirring any air-bubbles clinging to the drill-holes, those that sink are almost certainly of the cultured kind. While this test is not completely trustworthy, it is easily and quickly made, and at least provides a useful preliminary means of discrimination between cultured and native pearls.

D. IMITATION PEARLS

Owing to the high prices that pearls of good quality have for centuries commanded, efforts to imitate them go back a long way. A process which met with considerable success was invented in the middle of the seventeenth century (in 1656) by a French rosary-manufacturer, by name Jaquin, and has been almost continuously in use ever since. It consists of small hollow spheres formed of an easily fusible, opalescent glass. The inner side of the thin shells is lined with parchment size to which is fixed the pearl essence (*essence d'orient*), which is a preparation made from the silvery scales of the bleak, a small fish (*Alburnus lucidus*) that lives in the Seine and other European rivers. As soon as the lining is dry, the interior is filled with hot wax to impart the requisite solidity

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[1] Such a liquid may be prepared by correctly mixing bromoform (density 2·9 and monobromonaphthalene (density 1·5). A suitable hydrometer will be required for checking the density.

and weight. The general effect of these hollow pearls, as they are termed, is very good, but they are easily recognized by their greater smoothness and hardness and by the apparent doubling of, say, a spot of ink placed upon the surface, owing to reflection at the inner surface of the glass shell.

Another kind of imitation pearl, which is more usual nowadays, consists of beads that are coated with iridescent material. The beads may be made of glass, mother-of-pearl, celluloid or other substance, and the coat may be composed of various substances. Thus the pearl essence affixed by means of a varnish has been used with better effect than when applied inside hollow spheres. Rhythmical deposition of gelatine gives good results. In the cheapest kind the beads are merely dipped into a cellulose solution. However well this kind of imitation pearl be made, it suffers from the drawback that the coat sooner or later shows signs of wear. Moreover, none of them stands close examination, because the character of the surface is quite different from the grained pattern characteristic of the nacreous coating supplied by a pearl-mollusc. Further, imitation pearls are easily detected by inspection of the edges of the drill-hole which almost invariably shows signs of peeling, thus revealing the glass bead within.

According to R. Webster the specific gravity of the hollow-bead type is extremely low, 1·55 or even less, but that of the solid-bead type is much higher, the usual range being 2·85 to 3·18, though lower values, 2·33 and in the case of better quality 2·53, have occasionally been met. If therefore imitation pearls be dropped into a liquid of density 2·74, the first type will rapidly rise to the surface, and of the second type most will sink to the bottom while a few will float.

Occasionally, black pearls are imitated by beads cut from the black mineral, haematite (p. 452). Coral, too, is sometimes cut into bead shape, in imitation of pink (conch) pearl, which has no iridescence; the latter may be distinguished by its characteristic surface markings as seen under the microscope and by its higher specific gravity.

As material for brooches, ear-rings or bracelets under the name of 'shell' or 'Chinese cat's-eye', despite the fact that it is devoid of chatoyancy, occasional use has been made of the operculum (a Latin word, meaning lid), that is the door of the shell, of a gastropod, *Turbo petholatus*, which inhabits the warm seas north of Australia as far as Indo-China. Round or oval in shape and about ½ to 1 inch (12 to 25 mm.) in diameter, these lids are convex on the upper surface with a porcelain-like surface, the apex being coloured green and grading to yellow and white on the one side and through reddish- to dark-brown on the other, and are flat with spiral lines of growth on the base, which is covered with a skin. In composition they consist almost entirely of calcium carbonate, with usually less than 1 per cent of conchiolin and water. The specific gravity ranges from 2·70 to 2·76, and the hardness is $3\frac{1}{2}$ on Mohs's scale; a vague shadow-edge is discernible at about 1·57 in the field of a refractometer.

XL

IVORY, CORAL, JET AND TORTOISE-SHELL

A. IVORY

From time immemorial ivory has been highly valued by man because of its many convenient and attractive qualities: its pleasing creamy tint and compact texture, the ease with which it can be worked and shaped with ordinary metal tools, and its comparative durability, except for the yellowish discoloration which it may develop, especially if exposed to damp conditions. It is still esteemed to-day, though for many utilitarian purposes such as knife-handles and pianoforte-keys it has long been replaced by the cheaper celluloid, a prototype of the plastics, which is better able to retain its colour, though on the whole its tint is less pleasing. The word ivory has come to us through the old French *yvoire* from the Latin *eboreus*, the adjective corresponding to the noun *ebur*, which itself means ivory. Properly it is used for the tusks of the elephant, mammoth (differentiated as fossil ivory), hippopotamus, walrus, sperm-whale or cachalot, and narwhal or sea-unicorn, and less accurately for the teeth of the boar, such as the wart-hog, and for a vegetable substance which resembles the true ivory in general appearance. It should be noted that in fossil ivory no such silicification has occurred as is commonly characteristic of fossils, and in appearance and structure it differs little from ordinary elephant ivory. Unless suitably qualified, the term ivory should, however, be restricted to the tusks of the present-day elephant; mammoth tusks should be styled mammoth, or fossil ivory, and similarly one should speak of walrus ivory, and so on.

The dentine of elephant ivory, whether recent or fossil, is threaded with a multitude of minutely slender tubes that extend from the base towards the tip in a generally longitudinal direction in flat spirals of opposite hands. Transverse sections of tusks therefore usually, though not universally, show a pattern of intersecting arcs that suggests the engine-turning often seen on the cases of watches, though the arcs are seldom so mechanically perfect in curvature. This pattern is shown by elephant ivory and by no other kind, and, if present, identifies it beyond question.

Owing to the imperfect translucency of the material a measurement of the refractive index by means of a refractometer is attended with some difficulty. Values which have been obtained in this way vary from 1·520 to 1·550, the mean being 1·535. There is no such difficulty in determining the specific gravity, and from fifteen specimens Robert Webster obtained values ranging from 1·70 to 1·85, with a mean of 1·79. The hardness varies from $2\frac{1}{2}$ to $2\frac{3}{4}$ on Mohs's scale. Ivory-workers have, indeed, come by experience to recognize two types of ivory, which merge into each other: the one 'hard' or 'bright', which is distinctly more difficult to cut, and the other 'soft', which is easier to work, and at the same time is tougher and more resistant to changes of temperature. Fossil ivory has almost identical characters.

Like teeth in general, ivory fluoresces a violet-blue colour when excited by ultra-violet rays; fossil ivory displays a somewhat paler tint. Ivory will chip, if tested with the blade of a knife, unlike plastics, which are sectile.

Thin sections of ivory examined under a microscope reveal the undulating pattern of the minute tubes that spirally traverse the dentine from base to tip, together with in thicker sections series of parallel bands that cross the undulations from crest to crest. Sections including the outer coat or 'bark' of the tusk show a discontinuity of structure between it and the main mass. The undulations in the bark spread from the discontinuity surface, and are coarser, larger and more irregular than in the main mass. The bark also contains a host of seed-like dots which resemble the bone lacunae (p. 491).

In the case of hippopotamus ivory the refractive index is 1·545, and the specific gravity ranges from 1·80 to 1·95; the hardness also is slightly variable, ranging from $2\frac{1}{2}$ to $2\frac{3}{4}$ on Mohs's scale. The first two characters are slightly higher than those of elephant ivory. Hippopotamus ivory is remarkable for its retention of a thick coat or bark of enamel. It fluoresces a bright violet-blue colour, when excited by ultra-violet rays, and may be chipped with the blade of a knife. Under the microscope undulations similar to those of elephant tusks, but of perceptibly shorter wave-length (distance from crest to crest), are visible.

The cross-section of a walrus tusk is invariably characterized by a core of secondary dentine, which is conspicuously coarser in texture. This feature is peculiar to walrus, and, if visible, readily identifies its ivory. The refractive index varies from 1·55 to 1·57, the specific gravity from 1·90 to 2·00, and the hardness from $2\frac{1}{2}$ to $2\frac{3}{4}$ on Mohs's scale. The ivory fluoresces a bright violet-blue colour, when excited by ultra-violet rays, and may be chipped if tested with the blade of a knife. In a thin section under the microscope the usual undulations are visible, but in comparison with the previous instances they appear rather flattened, that is the amplitude of the waves is less, and the tubes are larger in diameter and show greater ramification.

The ivory from the sperm-whale, narwhal and wart-hog closely resembles walrus ivory in its characters except that the hardness is $2\frac{3}{4}$, $2\frac{1}{2}$ and $2\frac{3}{4}$ on Mohs's scale respectively; the fluorescent tints are also similar, that given by wart-hog ivory being still brighter. A thin section of sperm-whale ivory shows under the microscope a fine texture with scarcely perceptible undulations; a cross-section of a whole tooth exhibits a characteristic centre of secondary dentine. In the case of narwhal ivory the undulatory tubes have greater ramification than other ivories; and wart-hog ivory exhibits flattened undulations with short wave-length.

In addition to the abnormally developed teeth known as tusks the ordinary teeth of many animals, for instance, elephants, sharks and sperm-whales, have been strung together and worn as necklaces by primitive races. The molar teeth of elephants, when sliced, have been employed for many decorative purposes, such as knife-handles and the bases of ornaments. They display a characteristic structure: the vertical folds of dentine edged with enamel, approximately lozenge-shaped in the African elephant and elongated oval in the Indian elephant, stand out in their perceptibly whiter hue from the yellowish ground of cementum which fills the interstices of the folds. In course of time cracks may develop or the constituent parts may even separate.

Corozo-nut, which is the vegetable ivory supplied by the contents of the seed of the ivory plant of South America, consists of albumen, and is therefore the purest white in colour. It surpasses any of the animal ivories in the perfect uniformity of its texture, being free from marks of any kind, though in reality it is perforated by an infinite number of tiny holes, which are the sections of the corresponding cavities typical of the cellular growth characteristic of vegetation. When embedded in Canada balsam, it becomes all but invisible, having about the same refractive index, namely 1·538. Its specific gravity varies from about 1·40 to 1·43, which is appreciably below the range for animal ivories, and its hardness is $2\frac{1}{2}$ on Mohs's scale. It fluoresces the customary violet-blue of ivories, though a rather paler tint, and may be chipped if tested with a knife. Vegetable ivory appears to have become first known in Europe about 1826, soon after the Spanish-American Colonies revolted and ultimately gained their independence, and has long been used as material for fashioning into knobs, reels, thimbles, buttons, toys and small articles generally, both locally and in Europe and North America. The fresh liquid in the seeds provides a pleasant and refreshing drink for the passing wayfarer.

The doum palm differs from the ivory plant in providing a vegetable ivory that is initially solid; it is, however, less stable and unlike the corozo-nut may decompose in course of time. It has very nearly the same refractive index and hardness, though it is a little softer. Its specific gravity also is slightly lower, ranging from 1·38 to 1·40, the lower limit for corozo-nut; as would be anticipated, decomposed pieces have lower values, about 1·36. Immense quantities of the hard inner fruit-wall are used for the manufacture of buttons, and the seeds are cut into rosaries. Further, the hard tough wood is employed as the material for a variety of domestic articles.

BONE

Bone is not ivory, and is noticeably different in appearance; nevertheless, they are closely related, and a brief consideration of the characters of bone is not out of place as an appendage to the section of this chapter dealing with ivory.

Bones comprise the framework of all but the lowest of the animal kingdom. Bone-remains must have long been familiar to early man, and very soon the more solid kinds must have suggested themselves as suitable for ornaments or as material for fashioning into such objects; more recently bones have made a similar appeal to primitive races. As was pointed out above (p. 450), bones, like teeth, are composed of a mineral salt, calcium hydroxyl-phosphate and organic matter. On incineration of bone and consequent destruction of the organic constituent the mineral salt that remains is found to weigh about two-thirds of the original bone. On treatment by hydrochloric or nitric acid, which scarcely affects the organic matter, the mineral salt is removed, but the microscopic structure of the bone remains unimpaired, and it consequently follows that the mineral and organic ingredients are intimately intermingled.

According to their superficial appearance bones may be divided into two main categories, namely, compact and cancellated. The latter is spongy in structure, and is therefore ill-adapted to decorative purposes. It contains large interstices that are filled with fatty tissues, rich in blood vessels, and forms the interior of most bones as well as the ends of long bones. The compact variety, which forms the outer surfaces of all bones and the shafts of long bones, is dense enough to resemble ivory in appearance, and is therefore the kind that is selected for ornamental use. Microscopic examination of compact bone shows it to consist of a number of circular units, which are termed the haversian systems after the English anatomist, C. Havers, who first described them. The centre of each unit is void, being the section of the haversian canal, through which in life passed the artery and vein together with nerve fibres, capillaries and lymph space, all set in fatty tissue. The wall of the canal is formed of a series of concentric laminae of bone matrix, between them being bone lacunae, each filled with bone corpuscle, and across them being the fine branching lines of the canaliculi. Longitudinal examination shows that the canals frequently unite or at least communicate by oblique cross-channels. The interstices between the units are filled with bone tissue.

Compact bone has a slightly higher refractive index than ivory, ranging from 1·54 to 1·56, and also a somewhat higher specific gravity, ranging from 1·94 to 2·10; the hardness is $2\frac{3}{4}$ on Mohs's scale. These properties are therefore scarcely sufficient for certain identification. Compact bone may, however, be distinguished by its superficial appearance on examination with a microscope. If the surface be transverse to the length of the bone or nearly so, the circular or oval sections of the haversian systems, each surrounded by structure containing lacunae, will be visible. Longitudinal sections, on the other hand, display dark bands (the canals) in a mass of oval, seed-like lacunae. In no direction is there any suggestion of a grained structure.

B. CORAL

At the present day coral ranks far below pearl, and finds only a limited use for ornamental purposes; but, as Pliny tells us, in his day it held as high a place in India as pearl did in Rome,[1] and then as now it was the red coral that was valued.[2] We also learn from him that powdered

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[1] 'In the same degree that people in our part of the world set a value upon the pearls of India—a subject on which we have already spoken on the appropriate occasion at sufficient length—do the people of India prize coral.' (Quantum apud nos Indicis margaritis pretium est, de quibus suo loco satis diximus, tantum apud Indos in curalio.) Loc. cit., book 32, ch. 2.

[2] 'The reddest coral and the most branchy is held in the highest esteem; but, at the same time, it must not be rough or hard like stone; nor yet, on the other hand, should it be full of holes or hollow.' (Probatissimum quam maxime rubens, et quam ramosissimum, nec scabiosum, aut lapideum, aut rursus inane, et concavum.) Ibid.

coral was extensively used for medicinal purposes.[1] The name comes through the Latin from the Greek word *κοράλλιον* (coral).

As is well known, coral occurs widely in warm seas, and has given rise to the extensive coral-reefs which are such a conspicuous feature of tropical waters; but only one kind has ever been in general use either to adorn the person or to decorate weapons or implements, and that is the noble coral (*Corallium nobile* or *Corallium rubrum*), which is respectively rose-red or red in colour. Its composition is mainly calcium carbonate (about 85 per cent) together with a little magnesium carbonate and smaller amounts of iron oxide and other mineral substances, and a small amount (about 1 per cent) of organic matter, and its shape is branchlike. It is the calcareous framework of the coral polyp, and has been built up by a colony of these marine organisms, which have lived and died *in situ*, in the form of hollow tubes fitting the one within the other. The mineral matter is secreted from the sea by the polyp in its tissues, and left in place on its death. The calcium carbonate is in the form of calcite, and its crystals are arranged in fibrous fashion, radiating at right angles to the axis of the skeleton. The colour is mainly dependent upon the organic matter present. The specific gravity varies from 2·6 to 2·7, being slightly less than that of calcite, and the hardness is somewhat greater, being about $3\frac{3}{4}$ on Mohs's scale. In consequence of the large proportion of calcium carbonate in its composition, coral will effervesce in acids, even if only touched with a drop. Black coral, however, which has been used in China and in India, contains no calcium carbonate. The specific gravity of 1·32–1·35 and the refractive index of 1·56 indicate that this material is composed wholly of conchiolin.

Coral is generally fashioned into the form of beads, either round or egg-shaped. Owing to its comparative softness it readily lends itself to working with steel tools on a lathe or otherwise, and for the same reason at the best it only acquires a dull polish. The beads are bored, care being taken not to overheat them in the process, else they will crack; they are then strung for use as necklaces, rosaries or bracelets.

The best red coral has been found in the Mediterranean Sea from classical times, and has been valued in Italy since then. The most important localities are the coasts of Tunisia, Algeria and Morocco in Africa, the Calabrian coast of Italy, and around the islands of Sicily,

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[1] 'Calcined, pulverized, and taken in water, coral gives relief to patients suffering from griping pains in the bowels, affections of the bladder, and urinary calculi. Similarly taken in wine, or, if there are symptoms of fever, in water, it acts as a soporific.' (Contraque tormium, ac vesicae, et calculorum mala in pulverem igne redacti, potique cum aqua auxiliantur. Simili modo ex vino poti, aut si febris sit, ex aqua, somnum afferunt.) Ibid.

Sardinia and Corsica. The industry of working coral is centred almost entirely in Italy, and it is in that country that it is held in the highest esteem.

C. JET

For centuries, ever since the Roman occupation of Britain, the black compact material, known as jet, which has been found in considerable quantity on the Yorkshire coast near Whitby, has been worked and used for ornamental purposes, especially mourning jewellery. The name has come to us through the old French *jaiet* from the Latin *gagates*, itself taken from the Greek γαγάτης, which Pliny [1] tells us was taken from the name of either a place or river in the district in southern Asia Minor which was then known as Lycia.

Jet is a black variety of brown coal or lignite, which on account of its compact texture takes a good polish, and has resulted from the decomposition of drift-wood, which sank to the bottom of the sea and was embedded in the rock into which the fine mud was transformed. It occurs in the hard shales, known as jet-rock, of the Upper Lias on the coast near Whitby, and has also been mined in some of the neighbouring dales. Jet varies from about 1·30 to 1·35 in specific gravity, and from 3 to 4 on Mohs's scale of hardness.

At its best jet is uniformly black in colour, and will acquire a beautiful velvety polish. About the middle of last century jet jewellery was in some demand, but to-day it is little regarded, and for mourning jewellery harder black minerals, such as onyx, garnet (melanite) or tourmaline, are preferred.

Like any kind of coal, jet will burn, giving a sooty flame; it is, however, a test that for obvious reasons can be but sparingly applied.

D. TORTOISE-SHELL

The use of tortoise-shell for ornamental articles and particularly as a veneer and material for inlay dates back to about 80 B.C., for Pliny in his treatise on natural history says: 'Carvilius Pollio, a man of prodigal habits and ingenious in inventing the refinements of luxury, was the first to cut the shell of the tortoise into laminae, and to veneer beds and cabinets with it,' [2] and Carvilius Pollio held office as a Roman knight

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[1] 'Gagates is a stone, so called from Gages, the name of a town and river in Lycia.' (Gagates lapis nomen habet loci et amnis Gagis Lyciae.) Loc. cit., book 36, ch. 19.

[2] 'Testudinum putamina secare in laminas lectosque et repositoria his vestire Carvilius Pollio instituit, prodigi et sagacis ad luxuriae instrumenta ingenii.' Loc. cit., book 9, ch. 13. Repositoria appear to have been large trays for carrying dishes to the table, and so sideboards and cabinets in general.

(*eques*) during the dictatorship of Sulla,[1] 81–78 B.C. Later in his treatise, in the course of a discussion of the art of veneering, Pliny refers to the use of horns and ivory for decorating wood and to the curious practice of treating tortoise-shell so as to imitate wood:

> 'In order to make a single tree sell many times over, laminae of veneer have been devised; but that was not thought sufficient—the horns of animals must next be stained of different colours, and their teeth cut into sections, in order to decorate wood with ivory, and, at a later period, to veneer it all over. Then, after all this, man must go and seek his materials in the sea as well! For this purpose he has learned to cut tortoise-shell into sections; and of late, in the reign of Nero, there was a monstrous invention devised of destroying its natural appearance by paint, and making it sell at a still higher price by a successful imitation of wood.
>
> 'It is in this way that the value of our couches is so greatly enhanced; it is in this way, too, that they bid the rich lustre of the terebinth to be outdone, a mock citrus to be made that shall be more valuable than the real one, and the grain of the maple to be feigned. At one time luxury was not content with wood; at the present day it sets us buying tortoise-shell in the guise of wood.' [2]

Pliny included in the testudines all the order of reptiles now called Chelonia,[3] which are characterized by having the body enclosed in a bony case, the upper half being the carapace [4] and the lower half the plastron,[5] and by their jaws being toothless and covered with horny beaks. At the present day zoologists divide the order into land-tortoises (*Testudinidae*), marsh-tortoises (*Emydae*), river-tortoises (*Trionychidae*) and marine-tortoises (*Chelonidae*). The last group, which are distinguished by their feet having the form of flippers or paddles, are now usually called turtles; indeed, some writers restrict the name of tor-

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[1] Lucius Cornelius Sulla died in 78 B.C., at the age of sixty, soon after resigning the dictatorship.

[2] 'Ut una arbor saepius veniret, excogitatae sunt et ligni bracteae. Nec satis: coepere tingi animalium cornua: dentes secari: lignumque ebore distingui, mox operiri. Placuit deinde materiam et in mari quaeri. Testudo in hoc secta. Nuperque portentosis ingeniis principatu Neronis inventum, ut pigmentis perderet se, plurisque veniret imitata lignum. Sic lectis pretia quaeruntur: sic terebinthum vinci jubent, sic citrum pretiosius fieri, sic acet decipi. Modo luxuria non fuerat contenta ligno: jam lignum enim e testudine facet.' Claudius Nero, born A.D. 37, was Roman Emperor from A.D. 54 till his suicide in A.D. 68.

[3] From the Greek χελώνη (tortoise).

[4] From the Spanish *carapacho*, of doubtful etymology.

[5] From the Italian *piastrone, piastra* (breastplate).

toise to the land-tortoises. The aquatic tortoises, with a flat carapace and webbed feet, found in North America are known as terrapins (*Chrysemys*).

Both the words tortoise and turtle have originated from the late popular Latin name *tortuga*, which passed into English in several forms: tortuce, tortu, tortuse, tortose, the last finally becoming tortoise. Tortu, or possibly the French form *tortur*, was corrupted by English sailors into turtle. Terrapin is an old North American word for turtle.

The tortoise-shell of commerce is provided by the horny plates covering the bony carapace of the hawksbill turtle (*Chelone imbricata*), which is so named because the horny cover of its upper jaw forms a hooded beak which suggests the bill of a hawk. The hawksbill turtle is the smallest of the marine turtles, its carapace never exceeding 2 feet 6 inches (76 cm.) in length. There are altogether thirteen large plates, five down the centre and four on each side, and in addition twenty-four small plates, known as hoofs or claws, which form the serrated edge of the carapace. The large plates overlap from the front backwards, similarly to the slates on a roof from the ridge downwards, to the extent of about one-third of their whole size. Each of them may be as much as 8 by 13 inches (20 by 33 cm.) in size and 9 oz. (0·25 kg.) in weight. In old specimens, however, the plates may be flatter and lie in juxtaposition. It is the large plates which are coveted; the small ones on the edge of the carapace and the plates of the plastron underneath have little or no commercial value. One turtle can supply as much as 8 lb. (3·6 kg.) of tortoise-shell.

The plates are similar to ordinary horns in composition, being entirely devoid of mineral matter, but are appreciably harder, less fibrous and more brittle. Their value depends upon their translucency, the warmth of the pleasing yellow background, the richness of their mottled brownish colouring and the high degree of polish which they can receive and retain. The hawksbill turtle flourishes in all tropical seas in both the Pacific and the Atlantic Oceans, the choicest specimens occurring round the Moluccas in the Malay Archipelago.

Tortoise-shell is thermoplastic, that is, it softens under the influence of heat, at the temperature of boiling water. Inasmuch as it tends to darken and its translucency to diminish at too high a temperature, it is treated and worked at as low a temperature as possible. The plates are separated from the bony skeleton of the carapace by heat; as they are then curved, ridged and irregular in shape, they are flattened under pressure, while subjected to warmth, and surface inequalities that obtrude are filed away. The substance has the great advantage that the plates can so easily be enlarged either in surface size or in thickness, since sufficient heat will liquefy the superficial films of the surfaces to be united, and application of steady pressure will effect a perfect join. If it be intended to unite two plates by an edge of each, the edges in question are bevelled true and pressed together in a vice or by pincers, while warmed by boiling water or subjected to equivalent dry heat. By heat and pressure tortoise-shell may be moulded to form small boxes or other small articles. In modern times it has been cut into combs and shaped into knife-handles, and has long been a favourite material for the elaborate inlay of buhl furniture. Other tortoises supply plates, which are commercially known as turtle-shell, but they are little valued, because they are either opaque or soft and leathery; they cannot possibly be mistaken for the real substance.

The physical characters of tortoise-shell are as follows: refractive index about 1·55; specific gravity 1·29; and hardness $2\frac{1}{2}$ on Mohs's scale. It is sectile, if tested with a knife. If examined with a microscope the characteristic mottling is seen to contain numerous spherical particles. Stained horn and various plastics which are used to simulate tortoise-shell do not show this phenomenon.

XLI

RESINS

For countless years the exudations of trees, both resins and gums, have been used by man for a variety of purposes. The ancient Egyptians, for instance, were acquainted with the balsams and oleo-resins of North Africa, which they appear to have smeared on as a varnish, when warm; the varnish on mummy cases has survived in good condition to the present day.

Resins were extensively used in Roman civilization, and Pliny, in his great work on natural history, devotes considerable space to descriptions of the resin-producing trees, and of their qualities and uses. In the following passages he mentions six varieties:

> 'In those days they regarded as exotics, because they did not exist in the vicinity of the City, the pine and the fir, as well as all the other varieties that produce pitch; of which we shall now proceed to speak, in order that the method of seasoning wine, from the very first, may be fully known. Whereas there are several among the trees already mentioned in Asia or the East, that produce pitch, in Europe there are but six varieties of kindred trees that supply it. In this number there are the pine and the pinaster, which have long thin leaves like hair, and pointed at the end. The pine yields the least resin of them all; in the pine nut, indeed, of which we have previously spoken, it is sometimes to be found, but hardly in sufficient quantities to warrant us in reckoning the pine among the resinous trees.
>
> 'The pinaster is nothing else but a wild pine: it rises to a surprising height, and throws out branches from the middle, just as the pine does from the top. This tree yields a more copious supply of resin than the pine: the mode in which this is done we shall set forth on a future occasion. It grows also in flat countries. Many people think that this is the same tree that grows along the shores of Italy, and is known as the tibulus; but this last is slender, and more compact than the pine; it is likewise free from knots, and hence is used in the construction of light galleys; they are both almost entirely destitute of resin.

'The pitch-tree loves the mountain heights and cold localities. This is a funereal tree, and, as an emblem of death, is placed before the door of the deceased, and is left to grow in the vicinity of the funeral pile. Still, however, it is now some time since it was admitted into our gardens, in consequence of the facility with which it is clipped into various shapes. It gives out considerable quantities of resin, which is intermingled with white granulations like pearls, and so similar in appearance to frankincense, that, when mixed, it is impossible to distinguish them. . . .

'The fifth kind of resinous tree has the same localities, and is very similar in appearance; it is known as the larch. The wood of this tree is far more valuable, being unimpaired by time, and proof against all decay; it is of a reddish colour, and of an acrid smell. Resin flows from this wood in still greater quantities; it is of the colour of honey, more viscous than the other varieties, and never turns hard.

'A sixth variety is the torch-tree, properly so called, which gives out more resin than any of the others, with the exception of the pitch-tree, but its resin is more liquid than that of the last. The wood, too, of this tree is more particularly employed for kindling fires and giving torch-light in religious ceremonials'.[1]

As the result of extensive and intensive study of natural resins, with the object either of improving them for the particular purpose for which they were required or of finding cheaper or more suitable substitutes, a remarkable profusion of synthetic resins has been discovered, especially

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[1] Loc. cit., book 16, ch. 16: 'Peregrinae tum videbantur, quoniam non erant suburbanae, pinus atque abies, omnesque quae picem gignunt, de quibus nunc dicemus, simul ut tota condiendi vina origo cognoscatur. Quaedem serunt in Asia, aut Orienti, e praedictis picem. In Europa sex genera cognatarum arborum serunt. Ex iis pinus atque pinaster folium habent capillamenti modo praetenue, lognumque, et mucrone aculeatum. Pinus fert minimum resinae, interdum et nucibus ipsis, de quibus dictum est, vixque ut adscribatur generi.' Ch. 17: 'Pinaster nihil aliud est quam pinus silvestris, mira altitudine, et a medio ramosa, sicut in vertice. Copiosiorem dat haec resinam, quo dicemus modo. Gignitur et in planis. Easdem arbores alio nomine esse per oram Italiae, quos tibulos vocant, plerique arbitrantur, sed graciles succinctioresque, et anodes, liburnicarum ad usus, paene sine resina.' Ch. 18: 'Picea montes amat, acque frigora: feralis arbor, et funebri indicis ad fores posita, as rogis virens: jam tamen et in domos recepta, tonsili facilitate. Haec plurimam resinam fundit, interveniente candida gemma, tam simili thuris, ut mixta visu discerni non queat. . . .' Ch. 19: 'Quinto generi situs idem, eadem facies: larix vocatur. Materies praestantior longe, incorrupta vis, mori contumax: rubens praeterea, et dolore acrior. Plumsculum huic erumpit lignoris, melles colore, atque lentiore, numquam durescentis. Sextum genus est teda proprie dicta, abundantior succo quam reliqua, parciore liquidioreque quam in picea: flammis ac lumini sacrorum etiam grata. . . .'

during the present century. To these synthetic resins the generic term plastics has been given. When one thinks of the innumerable useful and decorative articles manufactured of such materials, which have reasonable rigidity, the term may seem a little odd; nevertheless it is an appropriate designation, because whatever be the final form of the material at some stage in its manufacture it was truly plastic. The word comes to us through the Latin *plasticus*, from the Greek πλαστικός (that may be moulded).

It should be understood that the attribute hard, when used in connexion with the resins, either natural or synthetic, is to be interpreted in a relative sense; none of them can in fact compare in this respect with ordinary gemstones. The hardness of natural resins increases with age, but the oldest and hardest of them, amber, is perceptibly softer than calcite, which Mohs selected as the degree 3 of his scale, though it is harder than gypsum, degree 2. On the average the resins, when solid, are about as hard as gypsum, some being slightly harder and others slightly softer, and most of them may be scratched by the fingernail. Hardness, of course, is not a character to be recommended for discriminative purposes, but it serves as a guide to the purposes to which articles composed of resin may advantageously be put; thus, if transparent or even translucent, they should be handled and dusted with reasonable care, if they are to retain their original polish.

A. NATURAL RESINS

The natural resins which are or have been in common use have all, with the striking exception of shellac, originated from vegetation, being exudations from trees, either alone or mixed with an essential oil commonly oil of turpentine, and are distinguishable from the other kind of exudations from trees, gums, by their insolubility in water. It should be noted that the term gum is also used to include certain oleo-resins, which are fluid when fresh; kauri-gum is an example.

The specific gravities of the resins yielded by trees differ little from 1·060, and, inasmuch as the value in particular instances depends upon the extent of the inclusion of air, it is a property of little service for discriminative purposes. It is, however, sensibly lower for the natural than for the synthetic resins, with the single exception of shellac, which is not directly a tree product.

The refractive index, on the other hand, is a more reliable property, since it is unaffected by the inclusion of air pockets. The mean value, 1·530, is appreciably lower than the refractive index of the bulk of the transparent synthetic resins. In this respect shellac accords with the other natural resins.

The temperatures given as the melting points of solid natural resins should be regarded as approximate only, inasmuch as fusion is a gradual process, and there is an appreciable difference between the point at which the resin softens and that at which it liquefies. Amber alone of the natural resins has any real importance as a material suitable for shaping into decorative articles. Other resins occasionally used to imitate amber are also described below.

I AMBER

The fossil resin to which the name amber has been given is not homogeneous in character, but consists of different constituents, each of which is more or less soluble in such solvents as spirit, ether or chloroform, together with an insoluble bituminous substance, and on the average corresponds in composition to $C_{10}H_{16}O$. It is a true fossil, the trees that exuded it having no living representatives to-day, whereas trees of the species which provide Zanzibar copal are living now. Of all the natural resins it alone is at all commonly used for ornamental purposes, chiefly in the form of beads, and has been in almost continuous use in that way in Britain since the Bronze Age.

The name, amber, has come to us through the French from the late Latin word, *ambar*, which was taken from the Arabic, *anbar*. There has been considerable confusion between our amber and a very different substance, which is formed in the intestines of the sperm-whale, or cachalot, and is in such great demand as an important ingredient of the finest perfumes. Thus amber in French is *ambre jaune* (yellow amber), and their *ambre gris* (grey amber) has passed into English as ambergris. The term bastard amber is given to cloudy material. Yellow amber, which was used as a varnish by the Greeks, was romantically termed by them βερνίκη after the golden-haired Queen Berenice. The name passed into Latin as *bernix* and later became *vernix*, and eventually reached us as varnish.

We learn from Pliny that amber was well known and valued in ancient times.

> 'Next in rank that is, after crystal and murrhine (opal, or possibly porcelain) among the objects of luxury we have amber, an article which, for the present however, is in request among women only.' [1]

[1] 'Proximum locum in deliciis, feminarum tamen adhuc tantum, succina obtinent.' Loc. cit., book 37, ch. 2.

In the course of his lengthy description of its properties he mentions its faculty, on rubbing, for picking up pieces of material:

> 'When a vivifying heat has been imparted to it by rubbing it between the fingers, amber will attract chaff, dried leaves, and their bark, just in the same way that the magnet attracts iron.'[1]

This attractive property of amber was also familiar to the Greeks, and it is from their name for it, ἤλεκτρον, that our word electricity is derived. It may be noted that they applied the same name to argentiferous gold, containing between 20 and 30 per cent of silver, presumably because its colour was a paler yellow than that of gold. The term, electrum, is still used in mineralogy for native argentiferous gold.

That the origin of amber was understood in Pliny's time is clear from the following passage in his work:

> 'Amber is produced from a marrow discharged by trees belonging to the pine genus, like gum from the cherry, and resin from the ordinary pine. It is liquid at first, which issues in considerable quantities, and is gradually hardened by heat or cold, or else by the action of the sea, where the rise of the tide carries off the fragments from the shores of these islands. At all events, it is thrown up upon the coasts, in so light and voluble a form that in the shallows it has all the appearance of hanging suspended in the water. Our forefathers, too, were of opinion that it is the juice of a tree, and for this reason gave it the name of succinum: and one great proof that it is the produce of a tree of the pine genus, is the fact that it burns, when ignited, with the odour and appearance of torch-pine wood'.[2]

Inasmuch as the trees that yielded amber proper flourished in the Oligocene division of the Tertiary period and were extinct long before Pliny's day, in the account quoted there is obvious confusion between copal

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[1] 'Ceterum attritu digitorum accepta calorie anima trahunt in se paleas ac folia arida, quae levia sunt: ac ut magnes lapis, ferri ramenta quoque.' Loc. cit., book 37, ch. 3.

[2] 'Nascitur autem de fluente medulla pinei generis arboribus, ut gummi in cerasis, resina pinis. Erumpit humoris abundantia: densatur rigore vel tepore autumnali. Cum intumescens aestus rapuit ex insulis, certe in litora expellitur, ita volubile, ut pendere videatur, atque considere in vado: quod arboris succum esse prisci nostri credidere, ob id succinum appelantes. Pineae autem arboris esse indicis est pineus in attritu odor, et quod ascensum tedae modo ac nidore flagret.' Loc. cit., book 37, ch. 3.

from then living trees and amber. The meaning of the name *succinum* which the Romans gave to the substance is explained by its derivation from *succus* (juice).

That Pliny knew of the inclusions in amber, and appreciated their significance is revealed by a later passage in his work:

> 'One great proof that amber must have been originally in a liquid state, is the fact that, owing to its transparency, certain objects are to be seen within, ants for example, gnats, and lizards. These, no doubt. must have first adhered to it while liquid, and then, upon its hardening, have remained enclosed within'.[1]

Amber is naturally yellow in colour, the depth varying from a pale shade to a brown one; the latter kind exhibits a fine blue fluorescence. It may be artificially stained other colours, such as black and green, and variegated colouring is practicable. Though hard compared with the other natural resins, amber is much softer than the gemstones, its hardness being about 2½ on Mohs's scale, and it may therefore just be possible to scratch it with the finger-nail, which itself is not constant but varies with the individual. It is not brittle, and therefore provides material that is very suitable for carving. Like all resins it has an amorphous structure and is consequently singly refractive, the index varying from 1·539 to 1·545, but it is always in a state of strain sufficient to show bright interference-colours in polarized light. The specific gravity varies from 1·05 to 1·10, and therefore amber will sink in pure water but float in a dense enough brine; in the passage quoted above Pliny refers to the apparent suspension of amber in sea-water. Being a very bad conductor of heat, amber feels warm to the touch. It develops negative electricity when rubbed, and, as was remarked above, when so treated it will pick up bits of material; like resins generally it forms a good insulator. Amber is frequently turbid owing to the presence of air-bubbles, and, as Pliny had noted, it often contains included matter, both organic and inorganic; the insects and other small animals which were caught by the resin when it exuded and have thus been preserved provide evidence of the utmost importance in regard to life at that far distant epoch.

When heated at a temperature between 250° and 300° C., amber boils quietly after fusion, yields as distillates a reddish-brown oil (oil of amber), a crystalline solid (succinic acid), and a watery fluid, and

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[1] 'Liquidum primo destillare, argumento sunt quaedam intus translucentia, ut formicae, aut culices, lacertaeque, quas adhaesisse mustes non est dubium, et inclusas indurescenti.' Loc. cit., book 37, ch. 3.

leaves behind a black residue (amber colophony, or amber lac). The percentage amount of succinic acid present varies from 2½ to 8. The chemical formula of the acid is $C_2H_4(COOH)_2$. It was first obtained from amber by distillation in the middle of the sixteenth century, and much the same method is used to-day. The name is taken from the original Latin word of amber, *succinum*, which was adapted from *succus* (juice). Succinic acid is responsible for the irritating aromatic fumes given off by burning amber.

Strictly speaking, the name amber should be confined to the variety succinite, which contains succinic acid. There are other fossil resins which contain none of the acid; gedanite, the name of which is derived from *Gedanum*, the Latin name for Danzig, is one of them. This variety is perceptibly softer, the hardness varying from 1½ to 2 on Mohs's scale, and the specific gravity is lower, ranging from 1·01 to 1·03. Burmite is an amber from the Myitkyina district of Burma, which is somewhat harder and denser than that from other localities.

Small pieces of amber, when heated with exclusion of air in an hydraulic press, can be kneaded together and formed into what is known as ambroid or pressed amber. This material is capable of being shaped into rods by being forced through circular holes of the requisite diameter in a metal plate. Pressed amber closely resembles the natural substance in appearance and physical properties; it may most easily be distinguished by the elongation of the contained bubbles, the general flow character of the structure and the pattern of the interference-colours, which are no longer uniform over a large field, but are in the form of a patchwork of contrasting tints.

The principal use of amber is as material for the mouthpieces of pipes, for cigar- and cigarette-holders, for necklace beads, and to a lesser extent for umbrella-handles and objects of virtu. Owing to its softness and toughness it is easily worked without risk of splintering, and it takes and retains a fairly good polish. The industry is mainly centred at Königsberg in what was East Prussia. Before the introduction of pressed amber small pieces of amber were used as material for varnish.

Amber may be closely imitated by certain synthetic resins, such as bakelite, the casein products erinoid and galalith, and celluloid (cellulose nitrate), but all these plastics are sectile under a knife applied in an inconspicuous spot, near the drill-hole of a bead for instance, whereas amber similarly treated splinters. Moreover, amber has a perceptibly lower specific gravity, and the smell of the fumes given off by fragments heated on the blade of a knife is usually characteristic.

In East Prussia amber occurs in extensive deposits in the marine glauconite sand called 'blue-earth' in the Lower Oligocene strata, which have been derived from earlier Tertiary deposits, the tree that produced it being *Pinus succinifer*, and also in the drifts which have resulted from its disintegration. It is washed up by the sea on to the coasts of eastern England, the Netherlands, Denmark, Sweden, Finland and the Baltic islands. Markedly fluorescent amber is found round the coast of Sicily. Other localities are Rumania and Burma.

2 DAMMAR

The resin which is bountifully provided by a variety of trees in the Malay Archipelago and southern India is known in Malay as *damar*, suitably qualified according to its character, but, inasmuch as the resin is chiefly used by the natives for torches, the name is taken by them to mean also torch. In European commerce, however, the name, usually spelt dammar, is restricted mainly to the fresh spirit-soluble resin, which is regarded as of inferior quality, the best of the harder sorts being included among the copals, for example Manila copal.

The fresh resin is exuded from the trees either naturally or by tapping. The only tree which is regularly tapped is *Belanocarpus heimii*, and its produce is known as *damar penak*, which is a clear, pale or yellowish, stalactitic resin of high quality. A resin of similar character, but globular and not stalactitic in form, known as *damar mata kuching* (cat's-eye dammar) is yielded by several species of the *Hopea* genus. The so-called Singapore dammar, which, however, is shipped from the port and is not produced in the island, is a mixture of the two resins mentioned; its refractive index is 1·515 and specific gravity 1·062. A similar resin from Borneo called Pontianak has a refractive index 1·545 and specific gravity 1·068; it melts at 135° C.

Much of the resin that comes into the market has been exuded from the tree a long time and has hardened into a more or less hard lump. Similar lumps are discovered in the earth, often in spots where now there is no trace of the parent trees. From their generally rock-like appearance these lumps are called *damar batu* (stone dammar), a term which locally is loosely used for all opaque and coloured pieces. Those black or very dark in colour are known as *damar hitam* (black dammar). In commerce these hard resins are included with the copals. The so-called Manila copal from the Philippine Islands has the following physical characters: refractive index, 1·544, specific gravity, 1·072 and the melting point, 120° C. (soft) and 190° C. (hard).

Vateria indica, a large evergreen tree of the Dipterocarpea genus, growing in southern India on the west side of the peninsula from

Kanara to Travancore up to a height of 4000 feet (1200 m.) above sea-level, produces a valuable resin called white dammar or piney resin.

3 COPAL

Copal, so called from the Mexican word *copalli* (incense), is the name given to solid resin of medium hardness, varying in tint from almost colourless to bright yellowish-brown and having a conchoidal fracture, which is soluble in suitable solvents, such as spirit and oil of turpentine, to an extent depending upon its age. It is fluid when fresh, but grows increasingly viscous with age, until it becomes solid and relatively hard. Copal comes from various trees in different parts of the world. The principal tree yielding it in tropical South America is the West Indian locust tree, *Hymenaea courbaril*, which is of considerable size, growing to as much as 100 feet (30 m.) in height and 25 feet (7·6 m.) in girth. The produce is mostly shipped to India and China, and does not reach the European market.

A well-known copal is kauri-gum, the resin of the kauri-pine, *Agathis australis*, enormous quantities of which are exported from New Zealand. The tree, which is an evergreen and is believed to be at least 3600 years old, is the largest forest tree of the North Island. The resin, however, is normally found in the form of nodules embedded to a depth of 2 to 3 feet (0·6 to 0·9 m.) in the gum-bearing soil, but of as much as 30 to 40 feet (9 to 12 m.) in the kauri-peat swamps, often far from trees now living. Kauri-gum melts at 150° C., and its refractive index is 1·540 and specific gravity 1·043. In appearance it is not unlike a pale amber, but being so much more recent in age it is far more susceptible to the attack of solvents; it is, for instance, rendered very sticky if a drop of ether be placed upon it, whereas amber so treated is hardly affected at all. Congo copal, from West Africa, is a somewhat harder resin, melting at a higher temperature, 200° C.; its refractive index is 1·540 and specific gravity 1·066.

A still harder resin and the hardest ordinarily used as a varnish is the Zanzibar or East African copal, which is termed the ripe, true or fossil copal. None of it is now collected on the island itself, mainly because more profitable employment is available for the natives, and practically the whole is obtained along the coast of the mainland, in Tanganyika, principally in the Bagamoya district, and round Rufigi to the south of Dar-es-Salaam and Lindi. It is found in the earth at shallow depths, not exceeding 4 feet (1·2 m.), usually as small pebbles but occasionally in masses about 4 lb. (1·8 kg.) in weight. Its refractive index is 1·515 and specific gravity 1·062; it softens at 158° and decomposes between 340° and 360° C., an oil distilling off with consequent alteration in the composition of the residue. It is partially soluble in spirit, but insoluble in hydrocarbons, esters and ketones.

4 SHELLAC

In two respects shellac stands out from all other natural resins: it is produced from the exudations of trees not directly but indirectly by the agency of an insect, and in its combination of high qualities as material for moulding and for electrical insulation it surpasses any other substance as yet known, whether natural or artificial. The resin itself is properly known as lac, the term shellac being applied to the product in the form in which it comes into the European market. Lac is the Hindustani word for a hundred thousand (100,000), but is commonly spelt lakh when used for that number; the name refers to the countless hosts of the insect which produces the resin. Shellac is the combination of shell and lac, being suggested by the form of the substance when offered for sale.

The resin is produced by one of the Coccidae or scale-insects, *Laccifer* (*Tachardia*) *lacca*, which is closely allied to the cochineal insect (*Coccus cacti*), kermes (*Coccus ilicis*) and Polish grains (*Coccus polonicus*), all of which, like it, yield a red dye. The lac insect in enormous numbers infests various trees, principally pipal (*Ficus religiosa*), pala or dhak (*Butea frondosa*), kusum (*Schleichera trijuga*) and ber (*Zizyphus jujuba*), occurring mainly in Bengal and Assam in India, and to a smaller extent in Burma, Siam and Indo-China. The insects are orange-red in colour, and vary from a fortieth to a twentieth of an inch (0·6–1·3 mm.) in length. Settling on suitable twigs, they absorb the juice of the tree, and exude a resinous secretion over their bodies, with the result that a cocoon is formed and finally a continuous resinous layer covers each twig. The males eventually succeed in emerging, but the females are trapped, and feeding hungrily are responsible for secreting the main bulk of the lac; at the same time the ovary sacs become enlarged and filled with a crimson fluid, the lac dye of commerce. About a month after the fertilization of the eggs the new brood appears and the life cycle is repeated. In view of the large and constant demand for shellac increase in the production is stimulated by cultivation and inoculation of suitable trees.

In the procedure for the production of shellac the infested twigs with the living insects are collected twice yearly, in June and December; this form is called stick-lac. After crushing and washing in hot water, the resin is melted and strained through thick canvas and spread out in layers; this is the form, known as shellac, in which the resin comes into the European market. In colour it varies from a dark yellow to black, but occasionally the tint is pale, and the resin, which then goes by the name of orange-lac, commands a higher price. Shellac can be bleached, being then known as white shellac, and can assume various delicate shades of colour by the addition of suitable tinctorial agents. In the East a favourite ingredient is orpiment (arsenic trisulphide, As_2S_3), a soft, lemon-yellow mineral. For orange-shellac the refractive index is 1·516 and specific gravity 1·152; the darker shellac is denser, and its specific gravity rises to about 1·42.

As is the general rule with resins there is an appreciable difference between the temperature at which shellac softens and that at which it melts, the former being between 62° and 68° C. and the latter being about 10° higher. Unlike any other natural resin it possesses distinct thermohardening properties, in this respect resembling the group of synthetic resins of which bakelite is the prototype: when heated to 100° C. it undergoes a permanent change, its solubility in spirit being markedly decreased and its melting point being raised.

In India shellac, when dyed yellow or other colours, is extensively used for the manufacture of bangles and other ornamental articles, and for coating articles made of other material, a process which is consequently known as lacquering. Splendid effects are obtained by pressing differently coloured sticks of shellac on to objects of suitable shape held on a revolving lathe, the heat developed by the friction being sufficient to melt the shellac and thus enable it to be spread in a thin film over the surface.

B. SYNTHETIC RESINS

The general use of synthetic resins in commerce originated about 1880 with the introduction of cellulose nitrate plastic, which was marketed as xylonite in this country and as celluloid in America. The use was greatly extended and enlarged by the introduction in 1909 of bakelite, the prototype of the unalterable form of plastics, which retain their rigidity permanently, and since that date development has been rapid with the discovery of other and even more attractive substances.

The formation of plastics was rendered possible by the phenomenon displayed by carbon compounds, which was named by J. J. Berzelius in 1830 polymerization. Polymeric substances have the same elements in the same proportions but different molecular weights, and their characters are different, and often strikingly so. Familiar instances are benzene, C_6H_6, which is a polymer of acetylene, C_2H_2; and acetic acid, $C_2H_4O_2$, lactic acid, $C_3H_6O_3$, and glucose, $C_6H_{12}O_6$, which are polymers of formaldehyde, CH_2O.

It may be noted that the synthetic resins, with the single exception of vinyl benzene plastic, are perceptibly denser than the natural resins, with the single exception of shellac. In the case of the refractive index there is much more overlap, the values for the natural resins lying within the range for the synthetic resins, but on the whole the glass-like synthetic resins have a perceptibly higher refractive index.

Considered from the point of view of the mode of working, plastics may be divided into two categories: thermoplastic and thermosetting. Plastics in the first category may be shaped and reshaped indefinitely by the application of suitable heat and pressure. They include the cellulose products and in addition the transparent vinyl, polystyrene and methacrylate resins, as well as the natural resins and waxes, which have already been considered. The second category comprises the phenol-formaldehyde, amine and casein plastics.

I THERMOPLASTIC RESINS

1 *Cellulose Nitrate Plastic*

Cellulose, the raw material of the cellulose plastics, is provided by the non-nitrogenous constituent of all plant walls, and is formed in the plant by sunlight. Strictly speaking therefore these plastics are not wholly synthetic. The largest source of cellulose is provided by the cotton-hairs or linters which remain after the long fibres used for spinning have been removed; their cellulose content is as high as 90 per cent. Wood pulp is another source which has recently been considerably developed.

So long ago as 1865 A. Parkes discovered that pyroxylin, a substance which corresponds nearly to cellulose dinitrate with 11 per cent of nitrogen, if well kneaded with camphor results in a horn-like substance, which was placed on the market under the trade name of xylonite. About the same time the brothers W. J. and J. S. Hyatt in the United States of America, stimulated by the offer of a prize for a substitute for ivory as the material for billiard balls, made a similar discovery. Their product was named celluloid. Other trade names that have been used are pyralin, hecolite, viscoloid and fiberoid. After the requisite colouring matter has been added the nitrate is calendered, cut into sheets, polished and shaped as may be suitable for the particular manufacturing purpose.

Celluloid is usually more or less translucent, and its physical characters are: refractive index, 1·495 to 1·520; specific gravity varying from

1·27 to 1·37 usually, but occasionally being as high as 1·90, depending upon the quantity and nature of the filling and colouring material; and hardness about 1½ to 2 on Mohs's scale. When tested with a knife, it is sectile and not powdered. It is soluble in acetone and to a small extent in amyl acetate, and is etched by concentrated nitric and sulphuric acids and also by caustic soda and other strong alkalis, but is unaffected by dilute acids.

With higher nitration pyroxylin passes into gun-cotton. It is therefore to be expected that celluloid suffers under the disability of easy inflammability. Nevertheless, despite this drawback celluloid finds an immense variety of uses, for instance, for pianoforte keys, knife handles, hairbrush backs, combs, toothbrush handles, fountain-pen barrels and ornamental articles generally, and the annual production throughout the world is enormous.

2 *Cellulose Acetate Plastic*

Consequent upon the danger arising from the inflammability of celluloid early investigations were made into the possibility of using as a plastic cellulose acetate, which does not burst into a flame, although it will burn slowly. Trade names which have been used are bexoid, celanese (for clothing), celastoid, cellomold, erinofoil, isoflex, lumarith, plastacele, rhodoid, tenite, utilex and windolite (on net).

Cellulose acetate resembles the nitrate in appearance, and has the following physical characters: refractive index, 1·47 to 1·50; specific gravity, 1·27 to 1·37, but rising to 2·00, according to the colouring agent used; and hardness about 1½ on Mohs's scale. It is sectile when tested with a knife.

3 *Vinyl Plastics*

An important series of plastics is provided by vinyl compounds, which contain the molecular group $CH_2 : CH$. The best known members of the group are polyvinyl acetate, $CH_2 : CH . O . CO . OH_3$, vinyl chloride, $CH_2 : CH . Cl$, a combination of the two, and polyvinyl benzene or styrene, $CH_2 : CH : C_6H_5$, in various polymerized forms, the properties depending upon the extent of polymerization, that is, of the linking up of the molecules.

Vinyl acetate is formed from acetylene, $CH : CH$, and acetic acid, $CH_3 . CO . OH$, as a liquid with a low boiling point, but on polymerization it is transformed into a transparent glass-like substance, which withstands heat, light and moisture, but is soluble in organic solvents. Its physical properties are as follows: refractive index, 1·473; specific gravity, 1·15. It softens at a low temperature, and is therefore suitable for moulding purposes.

Vinyl chloride is the result of the reaction of acetylene and hydrochloric acid, and is polymerized under various conditions. The properties vary considerably with the degree of polymerization; the low ones are soluble in many solvents, whereas the high ones are soluble only with difficulty, and soften at a high temperature. The interpolymers of vinyl chloride with vinyl acetate provide useful substances. If the proportion of the chloride be the greater, the polymers are colourless and transparent, and are useful for moulding purposes. The physical characters are as follows: refractive index is 1·52 to 1·53 and specific gravity 1·34 to 1·36, but with fillers rising to 2·5.

A most valuable plastic is provided by vinyl benzene or styrene, as it is commonly termed, which may be prepared by combining ethylene, $CH_2 . CH_2$, with benzene, C_6H_6, and cracking it, so that it loses hydrogen and yields styrene, $C_6H_5 . CH . CH_2$. It is then polymerized in various ways, and becomes transformed into a crystal-clear plastic with so high a dielectric strength that it may replace fused silica for radio frequency insulation. Polystyrene is manufactured under various trade names: distrene (in Great Britain), styron, lustron and victron (in America), and resoglanz and troletul (in Germany). It has the following physical characters: refractive index, 1·610 to 1·670; specific gravity, 1·05 to 1·07; and hardness 2¼ on Mohs's scale. It is sectile when tested with a knife.

4 *Methacrylate Plastics*

A remarkable series of glass-like plastics has been based upon the esterization of methacrylic acid. (The term esters was introduced by L. Gmelin for the products formed by the action of an alcohol and an acid whether organic or inorganic.) Acrylic acid is $C_3H_3O . OH$, and methyl acrylic acid (commonly contracted to methacrylic acid) is $C_4H''O . OH$. The polymerization of acrylic esters results in soft plastics, which cannot bear comparison in usefulness with the harder methacrylic esters.

Methyl methacrylate, $C_4H_5O . OCH_3$, is a remarkably clear substance, and constitutes the nearest approach to organic glass that has as yet been discovered. It has the following physical characters: refractive index, 1·50 to 1·52, specific gravity, 1·18 and hardness 2¼ on Mohs's scale. For the transmission of ultra-violet rays it is superior to glass, its dielectric strength is good, and it is resistent to inorganic acids and alkalis. It is marketed under the trade names: diakon, perspex, lucite and plexiglass. Combined with suitable colour fillers, it finds a use as the material for telephone sets, and, when colourless, its high degree of transparency renders it most serviceable in the manufacture of lenses.

II THERMOSETTING RESINS

1 *Phenol-Formaldehyde Plastics*

Although it was shown as long ago as 1872 by A. von Bayer that phenols and aldehydes would react to yield resinous products, the discovery was not put to practical purpose for many years, and it was not until 1909 that L. H. Baekeland, as the result of an extensive series of investigations, revealed that the product of the reaction between phenol and formaldehyde was a resin, which under suitable conditions set hard and was incapable of further deformation, and so opened a new epoch in the history of plastics. Instead of phenol cresylic acid may be employed. It consists of three distinct isomers of cresol, C_7H_8O, which is yielded by creosote, also a coal-tar derivative.

Phenolic moulding material is dark in colour, usually brown to black, but by the incorporation of suitable dyes red, blue and green tints are obtainable. Asbestos, mica and other minerals are used as fillers. The material is utilized for the manufacture of various articles, such as insulators, knobs, bottle-stoppers, panels for cabinets and ash-trays.

When cast phenolic resins are required, an excess of formalin is used. The resulting resin is tough, translucent and pale in colour. With the addition of a purple dye transparent, colourless material is obtainable, and variegated effects are produced by the mixture of differently tinted syrups before hardening.

The physical characters of phenol-formaldehyde resins are as follows: refractive index, 1·54 to 1·70; specific gravity, 1·35 to 1·60, depending upon the filler used (for the cast transparent type 1·27 to 1·32 and for the liquid stage 1·15 to 1·30); and hardness 2 to 2½ on Mohs's scale. The values for the cresylic acid-formaldehyde resins are: refractive index, 1·57 to 1·65; specific gravity, 1·12 to 1·20 (liquid stage); and hardness 2 to 2½ on Mohs's scale.

2 *Amine Plastics*

The not very attractive tints characteristic of the phenol-formaldehyde resins when first introduced led to intensive investigation into the possibility of obtaining brighter resins from the reaction of formaldehyde with other organic compounds. The best of them were found to be urea and its sulphur analogue thio-urea, and their products are called the amine plastics or amino-plastics. (Amine is a contraction of ammonia and -ine.)

The reaction of urea and formaldehyde with ammonia as a catalyst and glycerine as a plasticizer produces a syrup, which after suitable treatment is transformed into a tough transparent substance, resembling glass in appearance. Moulding powders and laminated products are also available. Similar material is produced if thio-urea, $CS(NH_2)_2$, be substituted for urea.

The glass-like plastic is named pollopas in Europe and aldur in America. It is apt to become dull on exposure to moisture, but its resistance may be strengthened by the incorporation of cellulose, up to 30 to 40 per cent, as a filler; though now no longer transparent, it is translucent, and by means of suitable dyes will take up a wide range of colours. In powder form with wood-pulp as a filler the material produces beetle-ware with a wide range of attractive colours; rather paler shades are yielded by scarab moulding powder with wood-flour as the filler. The physical characters are as follows: refractive index, 1·55 to 1·62; specific gravity: transparent, 1·425; scarab, 1·45 to 1·60; beetle, 1·49 to 1·63; pollopas, 1·50 to 1·60; and hardness 2¼ on Mohs's scale. It is sectile when tested with a knife.

These amino plastics have a wide range of uses, including table-ware, lamp-shades, cabinets, toilet articles, clock cases, bottle-stoppers and moulded buttons.

3 *Casein Plastics*

Apart from cellulose the only protein which has provided the raw material for plastics is casein. The trade names for this plastic are erinoid, lactoid or galalith. The physical characters are as follows: refractive index, 1·55; specific gravity, 1·325 to 1·345; and hardness 2 to 2¼ on Mohs's scale. It is sectile when tested with a knife. In a flame this plastic chars readily, giving off an unpleasant smell of burning protein.

Casein plastics may be worked in precisely the same manner as ivory or horn. It is the most outstanding of the coloured plastics, and finds an extensive demand as the material for buttons, buckles, cutlery handles, combs, spectacle frames, umbrella handles, fountain-pen barrels, fancy goods, electrical units and, indeed, anything which is not too much exposed to moisture.

Part IV

IDENTIFICATION TABLES

INTRODUCTION

For convenience in the identification of gemstones the tables of the physical constants and other relevant information are brought together in this part. It may be emphasized that in the case of a faceted stone by far the most effective, as well as the quickest, test to apply is the determination of the optical properties by means of a refractometer. As has been shown (p. 63), careful observations with this instrument will yield in the most general case the values of the least and the greatest of the principal refractive indices and therefore also the maximum amount of double refraction, together with an estimate of the amount of the colour-dispersion. If the stone be not faceted, alternative methods of obtaining at least an approximation to the refractive indices are available. The dichroscope, spectroscope and Chelsea filter may, too, be usefully employed to provide confirmatory or alternative tests; even a negative result with the refractometer is not without value, since it will serve to rule out certain possible species. If the stone be unmounted, a test for specific gravity may be quicky applied by the method of heavy liquids (p. 125); although less discriminative than the optical properties, this test may be relied upon in skilled hands to give in most instances satisfactory results. A test for hardness is rarely advisable.

A. CHEMICAL COMPOSITION

(*a*) ELEMENTS	
Diamond	C
(*b*) HALOIDS	
Fluor	CaF_2
(*c*) SULPHIDES	
Blende	ZnS
Pyrites	FeS_2
Marcasite	FeS_2
(*d*) OXIDES	
Zincite	ZnO
Corundum	Al_2O_3
Haematite	Fe_2O_3
Cassiterite	SnO_2
Rutile	TiO_2
Anatase	TiO_2
Brookite	TiO_2
Quartz	SiO_2
Chalcedony	SiO_2
Opal	$SiO_2 + nH_2O$

(*e*) MULTIPLE OXIDES

Spinel	$MgAl_2O_4$
Chrysoberyl	$BeAl_2O_4$
Taaffeite	$MgBeAl_4O_8$

(*f*) CARBONATES

Calcite	$CaCO_3$
Smithsonite	$ZnCO_3$
Rhodochrosite	$MnCO_3$
Azurite	$Cu_3(OH)_2(CO_3)_2$
Malachite	$Cu_2(OH)_2CO_3$
Stichtite	$Mg_6Cr_2(OH)_{16}CO_3 . 4H_2O$

(*g*) SILICATES

Zircon	$ZrSiO_4$
Olivine	$(Mg,Fe)_2SiO_4$
Phenakite	Be_2SiO_4
Willemite	Zn_2SiO_4
Dioptase	H_2CuSiO_4
Enstatite	$(Mg,Fe)SiO_3$
Diopside	$CaMg(SiO_3)_2$
Nephrite	$Ca_2(Mg,Fe)_5(OH)_2(Si_4O_{11})_2$
Spodumene	$LiAl(SiO_3)_2$
Jadeite	$NaAl(SiO_3)_2$
Rhodonite	$MnSiO_3$
Hemimorphite	$Zn_4(OH)Si_2O_7 . H_2O$
Talc	$Mg_3(OH)_2Si_4O_{10}$
Meerschaum	$H_4Mg_2Si_3O_{10}$
Serpentine	$Mg_6(OH)_6Si_4O_{11} . H_2O$
Sphene	$CaTiSiO_5$
Benitoite	$BaTiSi_3O_9$
Apophyllite	$KF . Ca_4Si_8O_{12}(OH)_{16}$
Chrysocolla	$CuSiO_3 + nH_2O$
Topaz	$Al_2(F,OH)_2SiO_4$
Andalusite	Al_2SiO_5
Fibrolite	Al_2SiO_5
Kyanite	Al_2SiO_5
Dumortierite	$Al(AlO)_7(BOH)(SiO_4)_3$
Pollucite	$H_2Cs_4Al_4(SiO_3)_9$
Haüynite	$(Na,Ca)_{4-8}(S_3,SO_2)_{1-2}(Al_6Si_6O_{24})$
Sodalite	$Na_8Cl_2(Al_6Si_6O_{24})$
Noselite	$Na_8(SO_2)(Al_6Si_6O_{24})$
Feldspar Family	
Orthoclase	$KAlSi_3O_8$
Microcline	$KAlSi_3O_8$
Albite	$NaAlSi_3O_8$
Anorthite	$CaAl_2Si_2O_8$
Scapolite Family	
Marialite	$Na_4Cl(Al_3Si_9O_{24})$
Meionite	$Ca_6(SO_4,CO_3)(Al_6Si_6O_{24})$

SILICATES—*continued*

Epidote	$Ca_2Al_2(AlOH)(SiO_4)_3$
Prehnite	$H_2Ca_2Al_2(SiO_4)_3$
Chlorastrolite	$Ca_2Al_3(OH)Si_3O_{12} . H_2O$
Thomsonite	Hydrated silicate of calcium, sodium and aluminium
Danburite	$CaB_2(SiO_4)_2$
Euclase	$Be(AlOH)SiO_4$
Axinite	$HMgCa_2BAl_2(SiO_4)_4$
Datolite	$Ca(B . OH)SiO_4$
Tourmaline	$(Na,Ca)(Li,Mg,Fe,Al)_9B_3Si_6(O,OH)_{31}$
Idocrase	$Ca_6Al(AlOH)(SiO_4)_5$
Staurolite	$HFeAl_5Si_2O_{13}$
Beryl	$Be_3Al_2(SiO_3)_6$
Cordierite	$(Mg,Fe)_2Al_4Si_5O_{18}$
Garnet Family	
Grossular	$Ca_3Al_2(SiO_4)_3$
Pyrope	$Mg_3Al_2(SiO_4)_3$
Almandine	$Fe_3Al_2(SiO_4)_3$
Spessartite	$Mn_3Al_2(SiO_4)_3$
Andradite	$Ca_3Fe_2(SiO_4)_3$
Uvarovite	$Ca_3Cr_2(SiO_4)_3$
Kornerupine	$MgAl_2SiO_6$

(*h*) PHOSPHATES, BORATES, SULPHATES

Apatite	$Ca_4(CaF)(PO_4)_3$
Amblygonite	$LiAl(F,OH)PO_4$
Variscite	$AlPO_4 . 2H_2O$
Beryllonite	$NaBePO_4$
Lazulite	$FeAl_2(OH)_2(PO_4)_2$
Brazilianite	$NaAl_3(OH)_4(PO_4)_2$
Turquoise	$CuAl_6(PO_4)_4(OH)_8 . 5H_2O$
Hambergite	$Be_2(OH)BO_3$
Rhodizite	$KAl_2B_3O_8$
Sinhalite	$MgAlBO_4$
Wardite	$Na_4CaAl_{12}(PO_4)_8(OH)_{18} . 6H_2O$
Gypsum	$CaSO_4 . 2H_2O$

B. CRYSTAL SYSTEM

(a) *Cubic* Diamond, spinel, garnet, fluor, pollucite, rhodizite, blende, pyrites, haüynite, sodalite, noselite.

(b) *Tetragonal* Zircon, scapolite, idocrase, cassiterite, rutile, anatase, apophyllite, wardite.

(c) *Hexagonal* Beryl, apatite, taaffeite, benitoite (morphologically trigonal, see p. 37), zincite.

(d) *Trigonal* Corundum, tourmaline, quartz, phenakite, willemite, haematite, dioptase, smithsonite, rhodochrosite, stichtite, calcite.

(e) *Orthorhombic* Topaz, olivine, sinhalite, chrysoberyl, cordierite, beryllonite, hambergite, danburite, andalusite, fibrolite, kornerupine, enstatite, thomsonite, prehnite, brookite, hemimorphite, zoisite, staurolite, aragonite.

(f) *Monoclinic* Feldspar (orthoclase), spodumene, euclase, brazilianite, sphene, diopside, epidote, datolite, gypsum.

(g) *Triclinic* Feldspar (except orthoclase), axinite, kyanite, rhodonite, amblygonite.

(h) *Crystalline aggregates* Chalcedony, turquoise, variscite, chlorastrolite, wardite, serpentine, malachite, jadeite, nephrite, lapis-lazuli, sodalite, violane, azurite, lazulite, dumortierite, chrysocolla, rhodonite, talc (steatite), meerschaum; pearl, coral.

(i) *Amorphous* Opal, obsidian, tektite, silica-glass; amber, jet.

C. COLOUR

The grading of gemstones by colour cannot be very definite, and the divisions below are consequently wide, and include in each instance a large variety of shades; even in the first of them it will seldom happen that a faint tinge is not present. Thus the yellow category includes orange, the green category yellowish and greenish shades, the violet category purple and lilac, and the brown category yellowish and reddish shades.

(*a*) TRANSPARENT AND TRANSLUCENT

(1) *Colourless and White* Diamond, corundum, beryl (rare), chrysoberyl (rare), topaz, spinel (usually synthetic), tourmaline (achroite, rare), zircon (fired), quartz, opal (rare), feldspar (moonstone), spodumene, phenakite, beryllonite, apatite, hambergite, scapolite, danburite, datolite, pollucite, cassiterite (rare), kornerupine, fluor (rare).

(2) *Yellow* Diamond (also irradiated), corundum, beryl, topaz, tourmaline, zircon, chrysoberyl, quartz (citrine, cairngorm), garnet (grossular, spessartite, andradite), olivine, zircon (jargoon), feldspar (orthoclase), spodumene, apatite, phenakite, beryllonite, willemite, scapolite, danburite, datolite, axinite, brazilianite, rhodizite, sphene, cassiterite, rutile (synthetic), brookite, obsidian, silica-glass; amber.

(3) *Red* Diamond (rare), corundum (ruby), spinel, garnet (pyrope, almandine, spessartite), zincite, zircon, opal (fire-opal).

(4) *Rose and Pink* Corundum, beryl (morganite), topaz (fired), tourmaline (rubellite), quartz (rose-quartz), spodumene (kunzite), scapolite.

(5) *Green* Diamond (rarely natural, also irradiated), corundum, beryl (emerald, aquamarine) spinel, chrysoberyl (including alexandrite), garnet (grossular, andradite, uvarovite), tourmaline, olivine, zircon, quartz (prase, fired amethyst), spodumene (hiddenite), apatite, euclase, sphene, andalusite, fibrolite, datolite, kornerupine, enstatite, diopside, prehnite, dioptase, idocrase, epidote, rhodizite, clinozoisite, tektite, fluor.

(6) *Blue* Diamond (rarely natural, also irradiated), corundum (sapphire), beryl, topaz, spinel, tourmaline, zircon (heated), cordierite, benitoite, fibrolite, apatite, euclase, axinite (rare), kyanite.

(7) *Violet* Corundum, spinel, quartz (amethyst), spodumene (kunzite), apatite, scapolite, fluor, taaffeite.

(8) *Brown* Diamond (also irradiated), chrysoberyl, garnet (grossular), tourmaline, sinhalite, quartz (smoky-quartz), zircon (hyacinth), axinite, sphene, blende, cassiterite, rutile, anatase, andalusite, idocrase; amber.

(*b*) SEMI-OPAQUE AND OPAQUE

(1) *White* Chalcedony, calcite (marble), gypsum (alabaster), talc (steatite), meerschaum, pearl.
(2) *Yellow* (*metallic*) Pyrites, marcasite.
(3) *Red* Chalcedony (cornelian, jasper, bloodstone or heliotrope), coral.
(4) *Pink* Rhodochrosite, rhodonite, rhodizite, zoisite (thulite), stichtite, garnet (massive grossular), apophyllite, coral, pearl.
(5) *Green* Chalcedony (prase, chrysoprase, plasma), turquoise, variscite, wardite, serpentine, malachite, smithsonite, hemimorphite, idocrase (californite), jade (jadeite, nephrite), pseudophite, garnet, (massive grossular), quartzite (aventurine), smaragdite, chlorastrolite.
(6) *Blue* Lapis-lazuli, turquoise, sodalite, violane, fluor (blue-john), azurite, lazulite, dumortierite, chrysocolla.
(7) *Brown* Chalcedony, staurolite.
(8) *Black* Diamond, spinel, tourmaline, onyx, blende, cassiterite, haematite; jet.

D. REFRACTIVE INDICES

In the following table the gemstones are arranged in order of increasing refractivity. If only one value be given, the species is isotropic, that is, it may be cubic (crystalline) or amorphous (glass). If two values be given, the species is doubly refractive; in the case of a uniaxial stone they are the ordinary and extraordinary refractive indices, which is the higher and which the lower depending upon the optical sign, and in the case of a biaxial stone they are the least and greatest of the principal indices of refraction. The values given are the normal refractive indices corresponding to the yellow light of a sodium flame (5893 Å), and the digits in the brackets show the possible variation below and above those values which might be observed. Usually the normal value coincides with the arithmetic mean, but in certain instances—for example, spinel—it differs perceptibly from it, and two sets of digits are therefore given. In the case of fluor, quartz and calcite there is no variation, and the values quoted are accurate to the third place of decimals. If no variation be shown, the values must be regarded as approximate only, to the second or third place of decimals as the case may be. In every instance gem material alone has been considered; tourmaline, for example, may yield much higher refractive indices than those quoted, but such pieces are opaque, or nearly so, and therefore useless for jewellery purposes. In the case of cryptocrystalline substances only the shadow-edge which remains nearly steady in any position of the individual crystals is likely to be detected; the greatest of the principal refractive indices of turquoise, for example, will seldom be measurable.

Fluor		1·434 (±0·000)	
Opal		1·454 (±0·010)	
Silica-glass		1·462	
Sodalite		1·483	
Obsidian		1·495 (±0·015)	
Pollucite		1·521 (±0·004)	
Gypsum	1·520		1·530
Thomsonite	1·520 (±0·010)		1·531 (±0·013)
Stichtite	1·517 (±0·001)		1·543 (±0·001)
Feldspar (Orthoclase)	1·522 (±0·004)		1·530 (±0·004)
Apophyllite	1·535		1·537
Chalcedony		1·536 (±0·003)	
Cordierite	1·536 (±0·004)		1·544 (±0·004)
Amber		1·542 (±0·003)	
Quartz	1·544 (±0·000)		1·553 (±0·000)
Scapolite (Marialite)	1·545		1·555
Beryllonite	1·553		1·565
Scapolite (Meionite)	1·555		1·577
Talc	1·540		1·590
Variscite	1·56 (±0·01)		1·57 (±0·01)
Beryl	1·575 (±0·015)		1·582 (±0·017)
Hambergite	1·556 (±0·003)		1·628 (±0·003)
Wardite	1·590		1·599
Amblygonite	1·589 (±0·017)		1·612 (±0·023)
Odontolite		1·60 (±0·03)	
Brazilianite	1·598		1·617
Calcite	1·486 (±0·000)		1·658 (±0·000)
Nephrite	1·607 (±0·007)		1·634 (±0·007)
Prehnite	1·615		1·645
Lazulite	1·61		1·64
Turquoise	1·61		1·65
Hemimorphite	1·614		1·636
Aragonite	1·530		1·685
Danburite	1·630 (±0·003)		1·636 (±0·003
Topaz	1·630 (−0·022, +0·002)		1·638 (−0·022, +0·002
Tourmaline	1·622 (−0·002, +0·006)		1·640 (±0·005)
Andalusite	1·634 (±0·007)		1·644 (±0·004)
Apatite	1·637 (±0·005)		1·640 (±0·006)
Datolite	1·625		1·669
Phenakite	1·654		1·670
Jadeite	1·654		1·667
Euclase	1·658		1·677
Fibrolite	1·658		1·677
Spodumene	1·660 (±0·006)		1·675 (±0·006)
Dioptase	1·651 (±0·007)		1·703 (±0·006)
Enstatite	1·665		1·674
Kornerupine	1·667 (±0·002)		1·680 (±0·002)
Olivine	1·658 (±0·013)		1·696 (±0·013)

Dumortierite	1·678		1·689
Axinite	1·679 (±0·005)		1·690 (±0·006)
Rhodizite		1·69	
Sinhalite	1·670 (±0·005)		1·709 (±0·004)
Diopside	1·686 (±0·015)		1·712 (±0·015)
Willemite	1·691		1·719
Zoisite (Thulite)	1·700		1·706
Idocrase	1·708 (±0·008)		1·716 (±0·004)
Spinel		1·717 (−0·002, +0·030)	
Taaffeite	1·718 (±0·001)		1·722 (±0·001)
Kyanite	1·712		1·728
Rhodonite	1·733		1·744
Garnet (Grossular)		1·744 (±0·004)	
Garnet (Pyrope)		1·747 (±0·004)	
Rhodochrosite	1·601 (±0·004)		1·821 (±0·004
Chrysoberyl	1·745 (±0·004)		1·754 (±0·005)
Epidote	1·733		1·768
Corundum	1·765 (±0·005)		1·773 (±0·005)
Smithsonite	1·621		1·849
Benitoite	1·757		1·804
Azurite	1·730		1·838
Garnet (Almandine)		1·781 (±0·030)	
Garnet (Spessartite)		1·80 (±0·01)	
Malachite	1·66		1·91
Zircon (low)		1·81 (±0·03)	
Garnet (Uvarovite)		1·87	
Garnet (Andradite)		1·888	
Sphene	1·900 (±0·015)		2·020 (±0·030)
Zircon (high)	1·928 (±0·004)		1·987 (±0·004)
Cassiterite	1·997		2·093
Zincite	2·013		2·029
Blende		2·369 (±0·001)	
Strontium titanate		2·410 (±0·001)	
Diamond		2·419 (±0·002)	
Anatase	2·493		2·554
Brookite	2·583		2·741
Rutile	2·616		2·903
Silicon Carbide			

E. COLOUR-DISPERSION

The symbols *B–G*, *C–F* in the following table mean the difference between the refractive indices corresponding to the wave-lengths of the pairs of lines in the solar spectrum: *B* (6870 Å) and *G* (4308 Å); *C* (6563 Å) and *F* (4861 Å), respectively. The former interval covers nearly the whole of the visible spectrum, and is to be preferred, but the latter is the one usually quoted for optical glasses. For uniaxial gemstones the figures refer to the index of the ordinary ray, for biaxial to the value β.

	B–G	*C–F*		*B–G*	*C–F*
Fluor	0·007	0·004	Feldspar (Orthoclase)	0·012	0·007
Silica-glass	0·010	0·006	Pollucite	0·012	0·007
Beryllonite	0·010	0·006	Quartz	0·013	0·008

Beryl	0·014	0·008	Spinel	0·020	0·011
Topaz	0·014	0·008	Dioptase	0·022	0·013
Hambergite	0·015	0·009	Garnet (Almandine)	0·024	0·014
Phenakite	0·015	0·009	Garnet (Pyrope, Spessartite)	0·027	0·015
Chrysoberyl	0·015	0·009			
Fibrolite	0·015	0·009	Garnet (Grossular)	0·028	0·016
Euclase	0·016	0·010	Epidote	0·030	0·017
Danburite	0·016	0·010	Zircon	0·039	0·023
Datolite	0·016	0·010	Diamond	0·044	0·025
Scapolite	0·017	0·010	Benitoite	0·046	0·025
Tourmaline	0·017	0·010	Sphene	0·051	0·029
Spodumene	0·017	0·010	Garnet (Andradite)	0·057	0·032
Corundum	0·018	0·010	Cassiterite	0·071	0·041
Kornerupine	0·019	0·010	Blende	0·156	0·099
Idocrase	0·019	0·010	Strontium titanate	0·19	—
Kyanite	0·020	0·011	Rutile	0·28	—
Olivine	0·020	0·011			

F. CHARACTER OF REFRACTION

(*a*) SINGLE

Crystalline Diamond, spinel, garnet, pollucite, rhodizite, blende, sodalite, fluor, strontium titanate.

Amorphous Opal, zircon (metamict) obsidian, tektite, silica-glass; amber.

Diamond, metamict zircon and garnet frequently display locally a small amount of double refraction.

(*b*) DOUBLE

Uniaxial, positive

Apophyllite	0·002	Benitoite	0·047
Quartz	0·009	Dioptase	0·052
Wardite	0·009	Zircon (high)	0·059
Phenakite	0·016	Cassiterite	0·096
Willemite	0·020	Rutile	0·287

Quartz displays circular polarization.

Uniaxial, negative

Apophyllite	0·002	Tourmaline	0·018
Apatite	0·003	Scapolite	0·021
Taaffeite	0·004	Stichtite	0·026
Beryl	0·007	Anatase	0·061
Idocrase	0·008	Calcite	0·172
Corundum	0·008	Rhodochrosite	0·220
Zincite	0·016	Smithsonite	0·228

Apophyllite may be either positive or negative.

Biaxial, positive

Topaz	0·008	Chlorastrolite	0·015
Chrysoberyl	0·009	Spodumene	0·015
Enstatite	0·009	Euclase	0·019
Gypsum	0·010	Fibrolite	0·019
Feldspar (Albite)	0·011	Brazilianite	0·019
Rhodonite	0·011	Hemimorphite	0·022

Amblygonite	0·026	Hambergite	0·072
Diopside	0·026	Azurite	0·108
Prehnite	0·030	Sphene	0·120
Olivine	0·038	Brookite	0·158

Biaxial, negative

Danburite	0·006	Kornerupine	0·013
Feldspar (Orthoclase)	0·008	Kyanite	0·016
Cordierite	0·008	Amblygonite	0·030
Andalusite	0·010	Epidote	0·035
Rhodonite	0·011	Sinhalite	0·037
Axinite	0·011	Datolite	0·044
Beryllonite	0·012	Aragonite	0·155
Feldspar (Anorthite)	0·012	Malachite	0·254

Rhodonite and amblygonite may be either positive or negative. Iron-rich members of the olivine series are negative. The optical sign of the plagioclase feldspars is variable.

G. ABSORPTION-SPECTRA

Only the gemstones displaying conspicuous absorption-spectra and only the strong bands are noted here; fuller information will be found in the text (p. 100). Ångström units are used.

Fraunhofer lines	Zircon	Almandine	Pyrope	Ruby	Red Spinel	Alexandrite	
						Green Ray	Purple Ray
G 4308	4325			4685			
				4750			
F 4861	4840			4765	4900		
		5050					
E 5270	5375	5270	5200	5200			5400
	5625					5550	
D 5893	5895	5760		5950	5950		
			6200				6050
C 6563	6535					6400	
	6625						
B 6870	6910			6928 [1]	6840	6795	6774
				6942 [1]	6855		

H. SPECIFIC GRAVITY

In this table the gemstones are arranged in order of increasing specific gravity. In every instance the value quoted is the one which may normally be expected of gem material of the several species. Usually it coincides with the arithmetic mean, and in such case the

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[1] The doublet in the red of the absorption-spectrum of ruby is reversible, and appears as two bright lines, except by direct transmitted light, owing to the effect of fluorescence.

possible variation on either side of it is indicated by the single set of digits in the brackets that follow it. If, however, it differs from that mean, there are two sets of digits, which give the possible variation below and above the latter; thus, in the case of spinel the specific gravity is normally 3·60, but the possible range extends from 3·58 to 3·98. It will be noted that in the case of quartz and calcite the value quoted is constant to the second place of decimals. If no variation is shown, the value given is to be regarded as approximate only.

It must be borne in mind that the density of liquids is much more affected by variation in temperature than is the specific gravity of gemstones, and care must be exercised to ensure that the temperature of the liquid used does not seriously differ from that of the room, if an accurate determination of the specific gravity be required. In the case of the method of heavy liquids this difficulty may be obviated by the use of indicators of known specific gravity.

Amber	1·07 (±0·02)
Jet	1·32 (±0·02)
Meerschaum	2·00
Darwin-glass	2·07 (±0·22)
Opal	2·10 (±0·10)
Chrysocolla	2·10 (±0·10)
Stichtite	2·18 (±0·03)
Silica-glass	2·21
Sodalite	2·30
Gypsum	2·32
Hambergite	2·35
Thomsonite	2·35
Obsidian	2·40 (±0·07)
Apophyllite	2·40 (±0·10)
Serpentine	2·55 (±0·05)
Orthoclase	2·56 (±0·01)
Variscite	2·56 (±0·04)
Cordierite	2·59 (−0·01, +0·07)
Chalcedony	2·61 (±0·03)
Quartz	2·65 (±0·00) 2.651
Coral	2·65 (±0·05)
Scapolite	2·67 (±0·04)
Beryl	2·70 (−0·05, +0·15)
Calcite	2·71 (±0·00)
Pearl	2·71 (−0·03, +0·18)
Talc	2·75
Turquoise	2·80 (−0·20, +0·05)
Lapis-lazuli	2·80 (±0·10)
Wardite	2·81
Beryllonite	2·81 (±0·02)
Prehnite	2·87 (±0·07)
Pollucite	2·92 (±0·02)
Brazilianite	2·94
Aragonite	2·94 (±0·01)
Datolite	2·95 (±0·05)
Phenakite	2·96 (±0·01)
Nephrite	2·96 (±0·06)
Danburite	3·00 (±0·01)
Amblygonite	3·02 (±0·01)
Tourmaline	3·06 (±0·06)
Euclase	3·10
Lazulite	3·1
Odontolite	3·1 (±0·1)
Zoisite (Thulite)	3·12
Andalusite	3·15 (±0·03
Fluor	3·18 (±0·00)
Spodumene	3·18 (−0·01, +0·05
Apatite	3·20 (±0·03)
Chlorastrolite	3·2
Violane	3·23
Fibrolite	3·25
Enstatite	3·27 (±0·01)
Axinite	3·28 (±0·01)
Diopside	3·29 (±0·02)
Kornerupine	3·31 (±0·03)
Dioptase	3·31 (±0·04)
Dumortierite	3·31 (±0·05)
Jadeite	3·33 (±0·03)
Olivine	3·34 (−0·02, +0·16)
Epidote	3·40 (±0·10)
Rhodizite	3·40
Idocrase	3·40 (±0·05)
Hemimorphite	3·45 (±0·05)
Sinhalite	3·49 (±0·02)
Diamond	3·52 (±0·01)

Sphene	3·53 (±0·01)	Brookite	3·94 (±0·07)
Rhodonite	3·53 (±0·13)	Corundum	4·00 (±0·01)
Topaz	3·54 (±0·04)	Zircon (low)	4·02 (±0·08)
Spinel	3·60 (−0·02, +0·38)	Willemite	4·03 (±0·14)
Kyanite	3·67 (±0·02)	Almandine	4·05 (±0·15)
Benitoite	3·67 (±0·02)	Blende	4·09 (±0·01)
Staurolite	3·70 (±0·05)	Spessartite	4·16 (±0·04)
Grossular	3·70 (±0·10)	Rutile	4·21 (±0·03)
Rhodochrosite	3·70 (−0·24, +0·10)	Smithsonite	4·37 (±0·07)
Chrysoberyl	3·71 (±0·01)	Zircon (high)	4·68 (±0·03)
Pyrope	3·75 (±0·07)	Pyrites	4·93 (±0·09)
Uvarovite	3·77	Haematite	5·05 (±0·10)
Malachite	3·80 (±0·10)	Strontium titanate	5·13 (±0·01)
Azurite	3·83 (±0·06)	Zincite	5·68
Andradite	3·84 (±0·02)	Cassiterite	6·90 (±0·10)
Anatase	3·88 (±0·06)		

I. HARDNESS

It must be emphasized that the numbers given below denote a sequence of increasing hardness only, and have no other numerical significance whatever. For fear of damaging a worked stone the hardness test should be applied with the greatest possible care; in the case of a faceted stone it is wise to apply the girdle in an attempt to scratch a face of a known mineral, and not to attempt to scratch the stone itself. A finger-nail is about 2½ and will scratch gypsum; substances less than 2 in hardness are greasy to the touch. Window-glass is 5½, and a steel knife 6½; a hardened file is about 6¾ and therefore easily scratches glass, especially the softer kinds such as paste.

1. Talc.
1½. Stichtite.
2. Gypsum, chrysocolla (2–4), meerschaum.
2½. Serpentine (2½–4); amber.
3. Calcite, jet.
3½. Blende, azurite, aragonite; pearl.
3½. Coral.
4. Zincite, kyanite (4–6), malachite, fluor, rhodochrosite.
4½. Apophyllite.
5. Apatite, beryllonite, sphene, diopside, dioptase, datolite, obsidian, odontolite, variscite, wardite, smithsonite, hemimorphite, bowenite, lazulite.
5½. Opal (5½–6½), willemite, brazilianite, anatase, brookite, enstatite, thomsonite, chlorastrolite, moldavite, rhodonite (5½–6½).
6. Zircon (low type), feldspar, scapolite, amblygonite, rutile, prehnite, silica-glass, turquoise, lapis-lazuli, sodalite, violane, zoisite (thulite), strontium titanite.
6½. Garnet (andradite), olivine, sinhalite, benitoite, kornerupine, idocrase, epidote, pollucite, nephrite, cassiterite, pyrites, haematite.

7. Tourmaline, quartz, spodumene, cordierite, danburite, axinite, chalcedony, jadeite, dumortierite, staurolite.
7¼. Garnet (grossular, pyrope, spessartite), zircon (high).
7½. Beryl, garnet (almandine, uvarovite), euclase, phenakite, hambergite, andalusite, fibrolite.
8. Topaz, spinel, rhodizite, taaffeite.
8½. Chrysoberyl.
9. Corundum. 9½ Silicon Carbide.
10. Diamond.

J. CLEAVAGE AND PARTING

(*a*) CLEAVAGE

(1) *Octahedral* Diamond, fluor.
(2) *Dodecahedral* Blende, haüynite, sodalite.
(3) *Rhombohedral* Dioptase, smithsonite, rhodochrosite, calcite.
(4) *Basal* Topaz, willemite, zincite, apophyllite, wardite.
(5) *Pinacoidal*[1] Feldspar, olivine, cordierite, euclase, beryllonite, hambergite, fibrolite, kyanite, epidote, zoisite, gypsum, talc.
(6) *Prismatic* Spodumene, sphene, kornerupine, enstatite, diopside, hemimorphite, nephrite, jadeite, rhodonite, scapolite.

The number of cleavage planes is in (1) four, (2) six, (3) three, and (4) one.

(*b*) PARTING

(1) *Basal* Corundum.
(2) *Pinacoidal*[1] Enstatite, diopside.
(3) *Pyramidal* Sphene.

K. ANCILLARY TABLES

(*a*) CLERICI SOLUTION—WATER

Relation between Refractive Index and Density

Refractive Index	Density	Refractive Index	Density
1·670	4·023	1·580	3·263
1·660	3·939	1·570	3·178
1·650	3·854	1·560	3·093
1·640	3·770	1·550	3·008
1·630	3·685	1·540	2·923
1·620	3·601	1·530	2·838
1·610	3·517	1·520	2·753
1·600	3·432	1·510	2·669
1·590	3·348	1·500	2·584

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[1] A pinacoid, from the Greek word πίναξ (board), is a face that is parallel to two axes.

(*b*) METHYLENE IODIDE—BENZOL

Relation between Refractive Index and Density

Refractive Index	Density	Refractive Index	Density
1·740	3·304	1·670	2·601
1·730	3·205	1·660	2·502
1·720	3·106	1·650	2·403
1·710	3·007	1·640	2·304
1·700	2·908	1·630	2·205
1·690	2·809	1·620	2·106
1·680	2·710	1·610	2·007

(*c*) TEMPERATURE—DENSITY OF WATER AND TOLUOL

Temperature		Water	Toluol
Centigrade	Fahrenheit		
14°	57·2°	0·9993	0·871
15°	59·0°	0·9991	0·870
16°	60·8°	0·9990	0·870
17°	62·6°	0·9988	0·869
18°	64·4°	0·9986	0·868
19°	66·2°	0·9984	0·867
20°	68·0°	0·9982	0·866
21°	69·8°	0·9980	0·866
22°	71·6°	0·9978	0·865
23°	73·4°	0·9976	0·864

Toluol, or toluene (C_7H_8) is a colourless mobile liquid with a boiling-point of 111° C. at a barometric pressure of 760 mm. Commercial toluol varies slightly in density.

(*d*) WAVE-LENGTHS IN ÅNGSTRÖM UNITS: FRAUNHOFER LINES, FLAMES OR ARCS

A (O)	7606		
B (O)	6870	Mercury	6907
C (H)	6563	Lithium	6708
D_1 (Na)	5896	Cadmium	6438
D_2 (Na)	5890	Mercury	6234
E (Fe)	5270	Sodium	5896
b$_1$ (Mg)	5184		5890
b$_2$ (Mg)	5173	Mercury	5791
b$_4$ (Mg, Fe)	5168		5770
F (H)	4861		5461
G_1 (H)	4341	Thallium	5350
G (Ca, Fe)	4308	Mercury	4960
g (Ca)	4227		4916
h (H)	4102	Strontium	4607
H (Ca)	3969	Mercury	4358
K (Ca)	3934		4047

(*e*) BRITISH METRIC LENGTHS AND WEIGHTS

Inches	Millimetres	Feet	Centimetres
1	25	1	30·5
2	51	2	61·0
3	76	3	91·4
4	102	4	122·0
5	127	5	152·4
6	152	6	182·9
7	178	7	213·4
8	203	8	243·8
9	229	9	274·3
10	254	10	304·8
11	279	11	335·3
12	305	12	365·8

Yards	Metres	Miles	Kilometres
1	0·91	1	1·61
2	1·83	2	3·22
3	2·74	3	4·83
4	3·66	4	6·44
5	4·57	5	8·05
6	5·49	6	9·66
7	6·40	7	11·27
8	7·31	8	12·87
9	8·23	9	14·48

Oz. Av.	Grams	Lb. Av.	Kilograms
1	28·4	1	0·45
2	56·7	2	0·91
3	85·1	3	1·36
4	113·5	4	1·81
5	141·9	5	2·27
6	170·2	6	2·72
7	198·6	7	3·17
8	227·0	8	3·63
9	255·4	9	4·08

(*f*) CHEMICAL ELEMENTS

In the following table the commonly accepted combining weights of the elements, or atomic weights as they are usually termed, are based upon the hypothesis that the value for oxygen is exactly 16, the corresponding value for hydrogen being 1·008. For convenience of reference the arrangement is alphabetical. The symbols correspond to the English names of the elements, except in the following instances where they have been taken from the Latin equivalents: antimony (stibium), copper (cuprum), gold (aurum), iron (ferrum), lead (plumbium), mercury (hydrargyrum), potassium (kalium), tin (stannum) and tungsten (wolframium).

ATOMIC WEIGHTS

Element	Symbol	Atomic Weight
Aluminium	Al	26·97
Antimony	Sb	121·76
Argon	A	39·94
Arsenic	As	74·91
Barium	Ba	137·36
Beryllium	Be	9·02
Bismuth	Bi	209·00
Boron	B	10·82
Bromine	Br	79·92
Cadmium	Cd	112·41
Caesium	Cs	132·91
Calcium	Ca	40·08
Carbon	C	12·01
Cerium	Ce	140·13
Chlorine	Cl	35·46
Chromium	Cr	52·01
Cobalt	Co	58·94
Copper	Cu	63·54
Dysprosium	Dy	162·46
Erbium	Er	167·2
Europium	Eu	152·0
Fluorine	F	19·00
Gadolinium	Gd	156·9
Gallium	Ga	69·72
Germanium	Ge	72·60
Gold	Au	197·2
Hafnium	Hf	178·6
Helium	He	4·00
Holmium	Ho	164·94
Hydrogen	H	1·01
Indium	In	114·76
Iodine	I	126·92
Iridium	Ir	193·1
Iron	Fe	55·85
Krypton	Kr	83·7
Lanthanum	La	138·92
Lead	Pb	207·21
Lithium	Li	6·94
Lutecium	Lu	175·0
Magnesium	Mg	24·32
Manganese	Mn	54·93
Mercury	Hg	200·61
Molybdenum	Mo	95·95
Neodymium	Nd	144·27
Neon	Ne	20·18
Nickel	Ni	58·69
Niobium (Columbium)	Nb (Cb)	92·91
Nitrogen	N	14·01
Osmium	Os	190·2
Oxygen	O	16·000
Palladium	Pd	106·7
Phosphorus	P	30·98
Platinum	Pt	195·23
Potassium	K	39·09
Praseodymium	Pr	140·92
Radium	Ra	226·05
Radon	Rn	220·0
Rhenium	Re	186·31
Rhodium	Rh	102·91
Rubidium	Rb	85·48
Ruthenium	Ru	101·7
Samarium	Sm	150·43
Scandium	Sc	45·10
Selenium	Se	78·96
Silicon	Si	28·06
Silver	Ag	107·88
Sodium	Na	22·99
Strontium	Sr	87·63
Sulphur	S	32·06
Tantalum	Ta	180·88
Tellurium	Te	127·61
Terbium	Tb	159·2
Thallium	Tl	204·39
Thorium	Th	232·12
Thulium	Tm	169·4
Tin	Sn	118·70
Titanium	Ti	47·90
Tungsten	W	183·92
Uranium	U	238·14
Vanadium	V	50·95
Xenon	Xe	131·3
Ytterbium	Yb	173·04
Yttrium	Y	88·92
Zinc	Zn	65·38
Zirconium	Zr	91·22

PERIODIC TABLE OF THE ELEMENTS

Series	Group O	Group I	Group II	Group III	Group IV	Group V	Group VI	Group VII	Group VIII
1		H (1)							
2	He (2)	Li (3)	Be (4)	B (5)	C (6)	N (7)	O (8)	F (9)	
3	Ne (10)	Na (11)	Mg (12)	Al (13)	Si (14)	P (15)	S (16)	Cl (17)	
4 5	Ar (18)	K (19) (29) Cu	Ca (20) (30) Cu	Sc (21) (31) Ga	Ti (22) (32) Ge	V (23) (33) As	Cr (24) (34) Se	Mn (25) (35) Br	Fe (26), Co (27), Ni (28)
6 7	Kr (36)	Rb (37) (47) Ag	Sr (38) (48) Cd	Y (39) (49) In	Zr (40) (50) Sn	Nb (41) (51) Sb	Mo (42) (52) Te	Tc (43) (53) I	Ru (44), Rh (45), Pd (46)
8 9	Xe (54)	Cs (55) (79) Au	Ba (56) (80) Hg	La (57), etc. (81) Tl	Hf (72) (82) Pb	Ta (73) (83) Bi	W (74) (84) Po	Re (75) (85) At	Os (76), Ir (77), Pt (78)
10	Rn (86)	Fr(87)	Ra (88)	Ac (89)	Th (90)	Pa (91)	U (92)	—	

The figures in brackets are the atomic numbers.
The rare earths beyond lanthanum, numbers 58–71, and the transuranium elements are omitted from this table.
The elements technetium, promethium and astatine, numbers 43, 61, and 85, probably do not exist in nature.

APPENDICES

A. GREEK ALPHABET

For the benefit of readers unfamiliar with the Greek letters and their Roman equivalents, they are listed below.

Α	(A)	α	(a)	Alpha	Ν	(N)	ν	(n)	Nu
Β	(B)	β	(b)	Beta	Ξ	(X)	ξ	(x)	Xi
Γ	(G)	γ	(g)	Gamma	Ο	(O)	ο	(o)	Omicron
Δ	(D)	δ	(d)	Delta	Π	(P)	π	(p)	Pi
Ε	(E)	ε	(e)	Epsilon	Ρ	(R)	ρ	(r)	Rho
Ζ	(Z)	ζ	(z)	Zeta	Σ	(S)	σ, ς	(s)	Sigma
Η	(E)	η	(e)	Eta	Τ	(T)	τ	(t)	Tau
Θ	(Th)	θ	(th)	Theta	Υ	(U)	υ	(u)	Upsilon
Ι	(I)	ι	(i)	Iota	Φ	(Ph)	φ	(ph)	Phi
Κ	(K)	κ	(k)	Kappa	Χ	(Ch)	χ	(ch)	Chi
Λ	(L)	λ	(l)	Lambda	Ψ	(Ps)	ψ	(ps)	Psi
Μ	(M)	μ	(m)	Mu	Ω	(O)	ω	(o)	Omega

Of the two small letters for s, ς is used at the end of a word, and σ in any other position. Initial vowels which are aspirated bear the following symbol: *αἱματίτης* (blood-like), haematite; if they be not aspirated the symbol faces the other way: *εἶδος* (form). If an aspirated word be not the first in a combined word, the aspirate is dropped; for example, the late Greek word *τετραέδρον* (tetrahedron), from *τετράκις* (four times) and *ἕδρα* (face). Some early writers therefore omitted the aspirate in the English word, but, when it was found necessary to coin other similar words, which had not been used in Greek, the aspirate was retained in all of them. The initial ρ is almost invariably aspirated, and in the transliteration the *h* follows: for example, rhodonite from *ῥόδον* (rose).

The transliteration into English does not always follow the equivalence given in the alphabet above; thus κ is often represented by a hard *c*, and υ by *y*, as for instance *κρύσταλλος*, crystal, and *βήρυλλιον*, beryl. The double vowels are seldom strictly transliterated, and we have haematite from *αἱματίτης* (blood-like), idocrase from *εἶδος* (form), and economy from *οἰκονομία* (household management). It will be noticed that Greek words are always accented.

B. BIRTHSTONES

The allocation of gemstones as appropriate birthstones to particular months was originally based upon their colour, and the species used have consequently varied from time to time. The following is the list recommended by the National Association of Goldsmiths of Great Britain:

Month	Colour	Gemstone
January	Dark red	Garnet
February	Purple	Amethyst
March	Pale blue	Aquamarine (or Bloodstone)
April	Colourless	Diamond (or Rock-crystal)
May	Bright green	Emerald (or Chrysoprase)
June	Cream	Pearl (or Moonstone)
July	Red	Ruby (or Cornelian)
August	Pale green	Peridot (or Sardonyx)
September	Deep blue	Sapphire (or Lapis-lazuli)
October	Variegated	Opal
November	Yellow	Topaz
December	Sky-blue	Turquoise

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The order of entry within each section is chronological, and determined (with the exception of the list of early works) by the date of publication of the *latest* edition. The date of the first edition is also given if known, but it has not been deemed necessary to list intervening editions in detail. Each work is entered under the heading considered most appropriate to its particular value, but the subdivisions of the classification are not mutually exclusive. Many of the general works of section 2, for example, include useful determinative detail; they often also give valuable information on methods of cutting and polishing, and historical details on this subject are to be found in the works of such writers as C. W. King and J. H. Middleton. The bibliography may be considered comprehensive, though not exhaustive. It does not include books of more general scope, or articles which have appeared in periodicals. It is hoped that the present arrangement will prove helpful in exploring the literature of gemstones.

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D. ADMISSIBLE NAMES

The names that follow have been based upon those approved by the Gemmological Association of Great Britain for use by jewellers, in order that any possibility of ambiguity or misunderstanding about the species meant may be avoided.

(1) Diamond (p. 257). The practice of using the terms brilliant and rose elliptically for diamond is to be deprecated because of possible ambiguity.
(2) Ruby, star-ruby; sapphire, star-sapphire, sapphire cat's-eye (p. 289). Sapphire is used for all colours except red.
(3) Chrysoberyl, cymophane or chrysoberyl cat's-eye; alexandrite (p. 361). Chrysolite should not be used for chrysoberyl.
(4) Spinel; pleonaste or ceylonite (black or very dark green); gahnospinel (zinc-rich blue) (p. 322).
(5) Topaz (p. 315). Even if qualified, this term must not be used for quartz.
(6) Emerald; aquamarine; beryl, shades of green other than emerald; heliodor or golden-beryl; morganite, rose-beryl or pink-beryl (p. 303).
(7) Zircon (p. 353). Hyacinth or jacinth should not be used.
(8) Tourmaline; tourmaline cat's-eye (p. 340).
(9) Garnet; almandine; pyrandine; rhodolite; pyrope; spessartite; grossular, grossularite, green-garnet, hessonite; andradite, demantoid, melanite; uvarovite (p. 328).
(10) Iolite, cordierite or dichroite (p. 395).
(11) Peridot (p. 347).
(12) Rock-crystal; amethyst; citrine (also for heat-treated amethyst), smoky-quartz; cairngorm, morion; rose-quartz (p. 366).
(13) Prase; quartz cat's-eye; aventurine-quartz, rutilated quartz; tiger's-eye, falcon's-eye (p. 368).
(14) Chalcedony; chrysoprase; cornelian; bloodstone, heliotrope; jasper; plasma; agate, moss-agate; black onyx (one colour), onyx (banded), sardonyx.
(15) Spodumene; hiddenite; kunzite (p. 416).
(16) Jadeite; chloromelanite; jade (p. 433).
(17) Nephrite, greenstone, jade, New Zealand jade (p. 431).
(18) Opal; white-opal; black-opal; fire-opal; water-opal; opal-matrix (p. 377).

(19) Feldspar; adularia, yellow orthoclase; moonstone; microcline, amazonstone, amazonite; sunstone, aventurine-feldspar; labradorite, black moonstone (p. 381).
(20) Lapis-lazuli (p. 436).
(21) Turquoise (p. 438).
(22) Fluor, fluorite, fluorspar; blue-john (p. 445).
(23) Pyrites, pyrite, iron-pyrites; marcasite (p. 451).
(24) Obsidian; moldavite (p. 421).
(25) Malachite (p. 449).
(26) Serpentine; pseudophite (p. 454).
(27) Amber (p. 500).
(28) Jet (p. 493).
(29) Coral (p. 491).
(30) Pearl, black-pearl, conch-pearl, pink-pearl, clam-pearl; cultured pearl (p. 464).

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Entries in bold type refer to main descriptions