

# INTRODUCTORY GEMOLOGY

BY

WEBSTER AND HINTON







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## INTRODUCTORY GEMOLOGY

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# INTRODUCTORY GEMOLOGY

A STUDY OF THE IDENTIFICATION  
OF GEMSTONES, PEARLS, AND  
ORNAMENTAL MINERALS

BY

ROBERT WEBSTER, F.G.A.

*Author of The Gemmologist's Pocket Compendium*

With Revisions for American Edition

By

VIRGINIA V. HINTON, C.G., F.G.A.

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## P R E F A C E

THE contents of this book were first published serially in *The Gemmologist*. Slightly extended, corrected and improved where necessary (facetted and polished, as it were) they are offered as an introduction to the fascinating study of gems and to complement the information and data contained in *The Gemmologist's Pocket Compendium*.

Essential methods of gem testing are explained concisely, the apparatus is fully described and, where possible, illustrated. A brief account of the gem species is given in semi-tabular form. *Practical Gemmology* has been kept within manageable size by omitting the more intricate, scientific tests, and long descriptive chapters on gems, all of which are available in existing text-books.

Students may safely use the chapters herein as stepping stones to higher things; jewellers will find reference to this small volume helpful.

Appreciation is expressed to Mr. B. W. Anderson and Mr. G. F. Andrews for their help in critically revising the proofs, and to Mrs. S. R. Bach and Dr. Edward Gubelin for permission to reproduce photomicrographs.

ROBERT WEBSTER.

WIMBLEDON,  
LONDON, S.W.19.

## FOREWORD

MR. WEBSTER, a member of the British jewellery industry, was the first qualified gemologist to prepare a book which specializes on *gemology* as distinguished from books which specialize on *gems*. His contribution was not only timely, but valuable to beginning students of the subject.

Originally published in England by the N.A.G. Press, as *Practical Gemmology*, it had received favorable attention and considerable distribution in North America before it was decided to revise and republish it in the United States, as an additional volume to the *Jeweler's Library*. For the reader unversed in the science of gemstones, it should prove an excellent introduction to that subject. To the many students who have completed the North American mail course in the Fundamentals of Gemology, it will serve as a first-class "refresher" of many important subjects.

This revised book should be of particular value to those jewelers and laymen who do not find the time to pursue the organized courses in gemology, or who find it difficult to understand the more complete textbooks written by mineralogists such as G. F. Herbert Smith and Edward H. Kraus.

Mrs. Hinton, a Certified Gemologist, and, like Mr. Webster, a practical jeweler, has supplied the revisions and additions to the text and photographs which make the book of more practical value to readers in the United States.

However, tables of hardness, specific gravity and refractive indices have not been harmonized with those of North American gemology, nor has the American spelling been substituted for such words as *jeweller*, *colour*, *lustre*, *fibre*, etc. On the other hand, the American spelling of *gemology* and *gemologist* has been substituted for the longer and more scholarly English spelling.

To Mr. Webster and the N.A.G. Press we are indebted for the opportunity, during war years, of adding this book to our *Jeweler's Library*.

GEMOLOGICAL INSTITUTE OF AMERICA.

Los Angeles, August 1, 1945

## CHAPTER I

### INTRODUCTION

GEMOLOGY, the science of gems, is comparatively a new-comer to the arts of learning. Despite the fact that it has a commercial aspect, it is a subject of absorbing interest to one and all alike. As the materials used for personal adornment throughout the ages are so varied, so are the true sciences to which the students must turn for assistance in the understanding of gem materials—and this combined knowledge forms the basis for the new science of gemology.

Since more than 90% of all gem materials are products of the mineral kingdom it is obvious that a definite knowledge is required of the sciences of mineralogy and geology. The chemist plays his part in the study of gems and counterfeits, while the basic methods of gem discrimination, as used to-day, depend upon the work of the great physicists from Newton onwards. The gem materials of animal origin, as exemplified by pearl, ivory and coral, and of the vegetable kingdom, by amber and jet, bring in the work of the zoologist, the biologist and the botanist.

In any study of gems it is usual, and indeed advantageous, to deal with the subject from the angle of the mineral gemstones, leaving those of animal and vegetable origin to fall into their allotted places as later discussions, a method which will be carried out in this series.

The first of the three cardinal virtues of a gemstone is undoubtedly beauty—through transparency and depth of colour as in the ruby and emerald, through colour only as in the turquoise, through purity and “fire” as in the diamond, and through “play of colour” as in the opal. Finally, there is the beauty brought out by the lapidary in cutting the stone, often latent until he gets to work.

For use as ornaments, a cut stone should be able to resist abrasive influences that tend to destroy its lustre, so that durability is the second of the cardinal virtues. Durability is governed by the hardness of the minerals, and gemstones are in general hard minerals. Paste (glass) is not durable; it is too soft to resist the abrasion of the sand and dust particles in the air and the chemical action of the sulphur in the atmosphere.

Often of far greater influence than either beauty or durability is the third virtue, rarity. A mineral may be fairly common yet really fine pieces suitable for cutting may be quite rare. An example of this is the emerald; a flawless emerald of fine colour is exceedingly rare and may command a higher price than the diamond. The law of supply and demand, often influenced by the caprice of fashion, governs to a certain extent the rarity of gemstones, for there are many stones which undeniably possess the qualifications of beauty and durability but which have little value at the moment owing to the lack of demand.

The division of gemstones into the classes *precious* and *semiprecious* is arbitrary. Use of *semiprecious* is discouraged by the American Gem Society as implying "second best." All precious and so-called semiprecious stones total less than five per cent of all minerals. When considered with *all* stones, so-called semiprecious stones are precious. Actually many so-called semiprecious stones are more valuable than inferior precious gems; for example, some alexandrites are worth far more than are many emeralds.

As gemstones are minerals and are found in rocks, a note on minerals and rocks is given briefly. Minerals, as a rule, have a more or less definite chemical composition, which can be expressed by a formula; and, like other chemical compounds, are homogeneous; while rocks may be defined as aggregates of several minerals, which may vary very much in their relative proportions and which may be, more or less, easily separated, *e.g.* common granite is a rock which is made up of three principal constituent and easily observed

minerals: feldspar, mica and quartz; each of these three minerals are definite chemical compounds and may be mixed in almost any proportion to form granite. Any study of minerals soon shows that many occur naturally in geometrical forms bounded by plane surfaces which are termed crystals, a name derived from the Greek *crystallos*, meaning ice. The Greek philosophers thought that the brilliant crystal of colourless quartz (rock crystal) was water turned to ice which had been compressed in the mountain regions to such an extent that permanent congelment had taken place. A study of these bodies does not appear, at first sight, to be of great importance in the science of gems, but nearly all gems are cut from crystals and the crystalline form is just an outward sign of an inward orderly arrangement of the molecules which build up the structure of any kind of matter.

These atoms, so small that no microscope can be devised that will allow them to be seen, are the smallest particles of a substance that still remains as the substance, viz. a molecule of water is the smallest particle of water that can still remain alone and preserve the character of water. The molecules in a crystal are arranged in accordance with a definite plan which differs with every kind of crystalline type; it is by the physical and optical effects caused by this orderly arrangement that the various gems can be differentiated from each other and from glass. Glass has no regularity in the arrangement of its constituent molecules, hence, it has no definite structure.

Crystals can weigh as much as several tons, or be so small and so packed together that even the most powerful microscope will not reveal their boundaries. Such material is termed crypto-crystalline, an example of which is carnelian. Material which possesses the definite internal molecular structure of a crystal but which does not show the outward geometrical form is termed massive crystalline material, and rose quartz is a well-known example. Material that possesses no orderly molecular arrangement is termed non-crystalline or amor-

phous. Glass is of this type and so are the natural and synthetic resins (amber and bakelite) and opal, which is a natural gem.

### ***Recapitulation***

The three virtues in a gemstone are Beauty, Durability and Rarity. A molecule is the smallest part of a substance which can retain the character of the substance.

A crystal is a mineral compound (or element) which occurs naturally in geometric forms bounded by plane surfaces which is an outward expression of a definite and orderly molecular arrangement.

Crypto-crystalline material is composed of an aggregate of microscopic crystalline individuals.

Crystalline material has the internal molecular structure of a crystal but does not show the geometrical form.

Amorphous or non-crystalline material has no orderly arrangement of its molecular structure.

### ***Test Questions***

1. Would you say that coral was a mineral?
2. Is rarity always due to a dearth of material?
3. Explain the fundamental difference between crystal and glass.

## CHAPTER II CRYSTALLOGRAPHY

THE study of crystals can rarely be visualized, by a novice student, as being of value to gem study and the drier parts are in consequence often skipped. It must be said at once that the study of crystals *is of fundamental importance*, for much of the later work could not be understood without the knowledge which elementary crystallography gives.

The study of crystals has not only a value in gem *testing*, but is an essential knowledge for the lapidary who cuts a stone from a crystal, for the different effect of light passing through a crystal in different directions may materially alter the resultant colour and beauty of the stone. Likewise the knowledge of cleavage directions in a crystal often allows it to be easily split in a certain way, so saving much time and labour in cutting, or to avoid having that direction of weakness which would be detrimental in a cut stone. Again a knowledge of crystal symmetry allows a rough crystal to be recognized as belonging to such and such a system, thus allowing the possibility of naming the species by eye inspection alone.

The faces of a crystal are arranged according to certain laws of symmetry which form the natural basis of the classification of crystals into thirty-two groups and six systems. These types of symmetry, with the exception of one, the axes of symmetry, may be discarded for the purposes of our study.

To describe the form of a crystal it is necessary to have certain fixed lines of reference from which can be measured the distance and inclination of the various faces, hence, we imagine lines of indefinite length running through the ideal crystal in certain definite directions and intersecting at the



centre of it at a point called the *origin* (fig. 1). These imaginary lines, of which three, and in one case four, are necessary to describe a crystal, are termed *crystal axes* and according to the relative lengths and inclinations of these axes are separated the various crystals into one or other of the six crystal systems.

#### THE SIX CRYSTAL SYSTEMS

THE CUBIC SYSTEM has three axes all at right angles to one another and all of equal length (see figs. 1 and 2a). The ideal

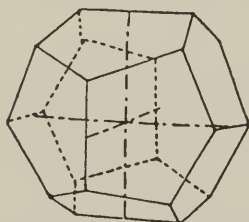


FIG. 1.—Crystal showing the axes. Example is pyritohedron of the cubic system

forms of the cubic system are the cube, the octahedron, the dodecahedron, etc. (fig. 2). In all crystals the combinations of two forms of the same system are common. Through inequalities of growth they rarely conform to the ideal crystal form. In each of the figures of crystals of the different systems an example is given of the combination of two forms and a

drawing of a natural crystal as found. This system is better known in America as the ISOMETRIC system.

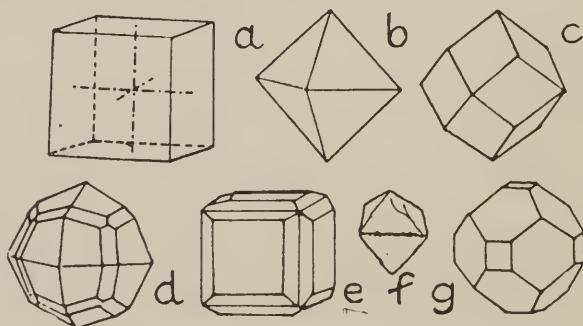


FIG. 2.—Forms of the cubic system. a, cube (showing axes). b, the octahedron. c, the rhombic dodecahedron. d, e and g, combination of forms. f, rough octahedral crystal of diamond



Gems which crystallize in the *cubic* system are :

Chromite.	Cobaltite.	Diamond.
Garnet.	Fluorspar.	Pollucite.
Pyrites.	Rhodizite.	Spinel.
Zinc-blende.	Sodalite.	Lazurite (lapis-lazuli).

THE TETRAGONAL SYSTEM has three axes, all of which are at right angles to one another, two of which are equal and one unequal in length. The unequal axis is vertical and is

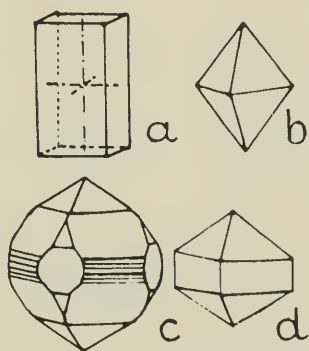


FIG. 3.—Forms of the tetragonal system. a, prism (showing axes). b, bi-pyramid. c, crystal of anatase. d, crystal of zircon. c and d illustrate combination of forms

known as the principal crystal axis, the equal axes are called the lateral axes. The ideal forms are a prism standing on a square base or two four-sided pyramids on square bases joined base to base (also called the DIMETRIC system) (fig. 3).

Gems which crystallize in the tetragonal system are :

Anatase.	Apophyllite.	Cassiterite.
Idocrase.	Rutile.	Scapolite.
	Zircon.	

THE ORTHORHOMBIC SYSTEM has three axes of unequal length which are at right angles to one another. The main

axis is placed vertically and the lateral axes pass through the sides; they are termed the *macro axis* for the longer of the two and the *brachy axis* for the shorter. The ideal forms are a prism on an oblong base (*i.e.* shaped like a matchbox) or the pyramidal form of four-sided pyramids with oblong bases

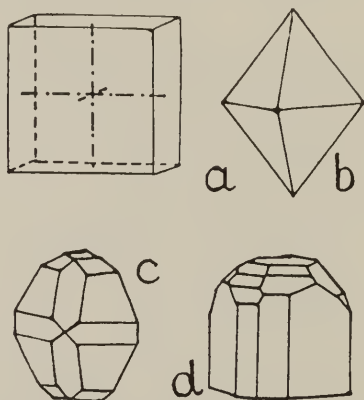


FIG. 4.—Forms of the orthorhombic system. a, prism (showing axes). b, bi-pyramid. c, combination of forms. d, crystal of topaz

placed base to base (also called the TRIMETRIC system) (fig. 4).

Gems which crystallize in the orthorhombic system are :

Andalusite.	Aragonite.	Beryllonite.
Bronzite.	Chrysoberyl.	Danburite.
Dumortierite.	Enstatite.	Fibrolite.
Hambergite.	Hypersthene.	Iolite.
Kornerupine.	Marcasite.	Peridot.
Prehnite.	Staurolite.	Thomsonite.
Topaz.	Variscite.	Zoisite.

THE MONOCLINIC SYSTEM has three axes, all of unequal length, two of which are at right angles to each other and the third inclined. One axis is placed vertically and of the

other two *lateral axes*, the one at right angles to the vertical axis is called the *ortho axis* and the axis which is inclined, the *clino axis*. The form may be better expressed by assuming a prism on an oblong base which has been pushed on one

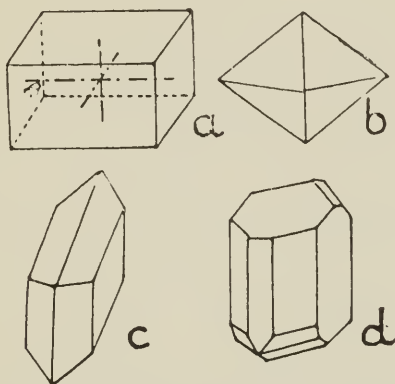


FIG. 5.—Forms of the monoclinic system. a, prism (showing axes). b, bi-pyramid. c, crystal of gypsum. d, combination of forms

side, making it lean over slightly in one direction only (fig. 5).

Gems which crystallize in the monoclinic system are :

Azurite.	Datolite.	Diopside.
Epidote.	Euclase.	Gypsum.
Jadeite.	Lazulite.	Malachite.
Meerschaum.	Nephrite.	Orthoclase feldspar.
Serpentine.	Spene.	Spodumene.
	Talc.	

THE TRICLINIC SYSTEM has three axes all inclined to one another and of unequal length. One axis is placed vertically and the two lateral axes are called the *macro* and *brachy* as in the rhombic system. The form may be recalled by the same form as in the monoclinic system with the difference the

push should be given to the edge so that the prism leans over both backwards and sideways (fig. 6).

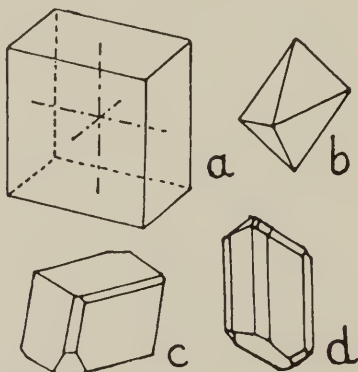


FIG. 6.—Forms of the triclinic system. a, prism (showing axes). b, bi-pyramid. c, crystal of axinite. d, combination of forms

Gems which crystallize in the triclinic system are :

Axinite.	Rhodonite.	Kyanite.
Turquoise.	Labradorite.	Microcline.
	Oligoclase feldspar.	

**THE HEXAGONAL SYSTEM:** There are two divisions of this system, the hexagonal and the trigonal. These are sometimes treated as two different systems. As the same set of axes apply to both divisions and the optical properties are similar they will be here treated as one system. This system has four axes. A vertical or principal axis which is longer or shorter than the other three, the lateral axes which are all of equal length and intersect at  $60^\circ$  with each other. The principal axis is at right angles to the plane containing the lateral axes. The ideal form is a prism on a six-sided base or the bi-pyramidal form of two six-sided pyramids on a common six-sided base. The six-sided figure, the *rhombohedron*, is also a form of this system (fig. 7).

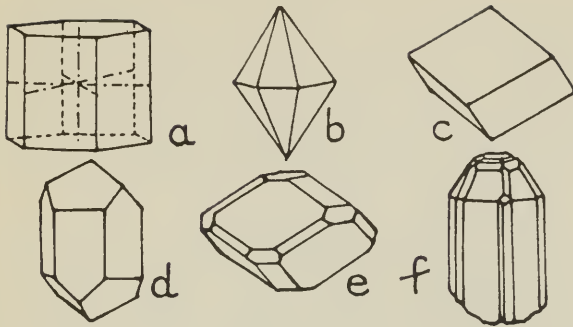


FIG. 7.—Forms of the hexagonal system. a, prism (showing axes). b, bi-pyramid. c, rhombohedron. d, crystal of calcite (showing combination of forms). e, crystal of iceland spar. f, crystal of apatite

Gems which crystallize in the hexagonal system are:

Apatite.	Benitoite.	Beryl.
Calcite.	Corundum.	Dioptase.
Elæolite.	Hæmatite.	Phenakite.
Quartz.	Smithsonite.	Tourmaline.
	Willemite.	

**TWIN CRYSTALS:** The crystals that have been discussed so far are single individuals; there are, however, occurrences of crystals which consist of two or more individuals and are known as *compound* or *twin crystals*. A *contact twin* is one in which the individuals are in contact along a common plane, the two parts of such a crystal are so related that if one-half is rotated through  $180^\circ$  about an axis, known as the *twinning axis*, it would bring them both into parallel position—*i.e.*, reform the two halves so as to make the shape of a single individual crystal. This form is typical of spinel and shows re-entrant angles, a common property of nearly all twin crystals. *Interpenetrant twins* are those in which the two individuals have so intergrown that they penetrate one another. This form may produce such cross-like twins as those of staurolite, which are better known in jewellery as

*cross-stones*, or *fairy-stones*. Repeated, cyclic or polysynthetic twins are composed of a number of microscopically small contact twins producing a number of very thin plates, each of which is arranged in opposite order to its fellow. This is sometimes called *laminar* or *lamellar twinning* and gives rise to such colour effects as are seen in labradorite and is also responsible

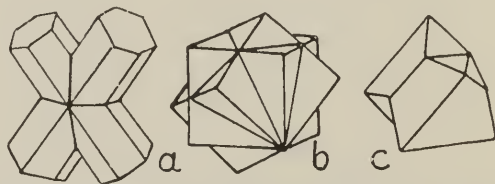


FIG. 8.—Twin crystals. a, interpenetrant twin of staurolite. b, interpenetrant twin of fluorspar. c, contact twin of spinel

for some of the *silk* effects.

### Recapitulation

The six systems of crystal architecture are:—Cubic; Hexagonal; Tetragonal; Orthorhombic; Monoclinic; Triclinic.

The Origin is the geometrical centre of an ideal crystal.

Twin crystals are two or more individuals which have grown together in such a way that their axes have some definite relation to one another. In general, they show re-entrant angles.

### Test Questions

4. In what way do the crystal axes differ in the cubic and tetragonal system?
5. What crystal systems have all their axes at right angles to one another?
6. What is a common property of nearly all twin crystals?

### CHAPTER III

## PHYSICAL PROPERTIES

THE first of the physical properties of gem materials is the phenomenon known as *cohesion*. Cohesion is the force of attraction which holds together the molecules of a substance and the stronger this force of attraction the more difficult is it to break the body. When a body is broken it is said to be *fractured*, and the surface of the fracture may be found to take one of several types. *Conchoidal* fracture shows a number of more or less concentric ridges which resemble the lines on sea-shells; this type of fracture is typical of rock crystal and glass. Other types of fracture are known as *smooth*, when the surface, without being absolutely plane, presents no marked irregularities; *splintery*, when the surface is covered with partially separated splinters in irregular fibres, an example is fibrous haematite; *hackly*, when the surface is covered with ragged points and depressions. Of far greater importance than fracture is *cleavage*, which is a direction of weakness along which, or parallel to which, if force be applied; a body will easily split. Cleavage is only possible in a crystal or in crystalline material and is due to the molecules making up the crystal being in regular layers (the orderly arrangement) and the force of attraction may be weaker between these layers than across them, hence, will break more readily along such directions; such a direction is known as the *cleavage plane* and is always parallel to a possible crystal face. Cleavage is of assistance in gem cutting or can be a disadvantage in that if an easily cleavable stone is dropped there is a great liability for it to break in two, or, if this major misfortune does not occur, to set up internal flaws which tend to destroy the transparency and with further rough handling increase in size.

Gems which have strong cleavage are :

Diamond.	Euclase.	Fluorspar.
Feldspar.	Sphene.	Spodumene.
Topaz.	Fibrolite.	Calcite.
Hambergite.	Peridot.	

#### HARDNESS

There is one other property of all substances which depends upon molecular cohesion, and that is the property termed *hardness*. Hardness may be defined as the power a substance possesses to resist abrasion (scratching) when a pointed fragment of another substance is drawn across it without sufficient pressure to develop cleavage. Experiment shows that a harder stone will scratch a softer object, and, based on this fact, the mineralogist Mohs devised a scale of reference which has been named after him. This is not a scale comparable with the 10 decimetres in a metre, but simply implies that topaz is softer than corundum, and fluorspar is harder than calcite. The intervals between numbers are *not* equal, in fact the difference in hardness between diamond (10) and corundum (9) is definitely greater than between corundum (9) and the softest—talc (1).

#### MOHS'S SCALE

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

(*Breithaupt proposed to interpolate Mica as 2.5 and Scapolite as 5.5, but they have not been generally adopted.*)

The softer numbers of the scale, Talc and Gypsum, may be scratched by a finger nail, and those up to 6 by a steel knife point, while Quartz and the higher numbers are all



harder than steel. Pointed fragments of the minerals in Mohs's scale numbers 6 to 10 are mounted in wooden or metal stems for use in gem testing. Working up from the softest to the harder points, the stone under test has applied to it the various *pencils* (fig. 9), a short line being scratched on an inconspicuous place (generally near the girdle) and the hardness of the stone will be between the two numbers which will not leave a scratch mark and the one that does. A test that was often resorted to in the early days of this century, it is now rarely used, more modern and safer scientific methods having adequately replaced the hardness test. In the United States, sets of polished plates of minerals of the hardness scale are popular. Through their use, the hardness of a gem may be determined with damage being done only to the test plate.

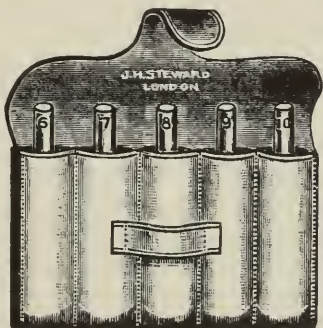


FIG. 9.—A set of hardness pencils in leather case. (J. H. Steward)

A short list showing the hardness of the most important gems is given under :

10. Diamond ;
9. Corundum (Ruby and Sapphire) ;
- 8½. Chrysoberyl (Alexandrite and Cymophane) ;
8. Topaz and Spinel ;
- 7½. Beryl (Emerald, Aquamarine, Morganite, and Golden Beryl) and Zircon ;

- 7 $\frac{1}{4}$ . Garnet;
7. Quartz (Amethyst, Citrine, and Rock crystal), Tourmaline and Jade (Jadeite);
- 6 $\frac{1}{2}$ . Spodumene (Kunzite and Hiddenite), Garnet (Demantoid), Jade (Nephrite);
6. Opal, Moonstone and Turquoise;
- 5 $\frac{1}{2}$ . Sphene;
5. Lapis lazuli.

Glass imitation gems have a hardness less than 6 on the scale <sup>1</sup>, and in general the more lustre and "fire" these stones have the softer they are, for in their manufacture the addition is made to the glass of small quantities of the oxides of lead and thallium which considerably softens it. Although on the scale diamond is marked as 10 and corundum (ruby and sapphire) as 9, it is found that stones from different localities may vary slightly in hardness. Diamond found in New South Wales (Australia) and Borneo are found to be harder or, at least, harder to cut than the stones from South America which are harder than those from South Africa. Ceylonese sapphires are said to be harder than the sapphires from Kashmir and all sapphires are understood to be somewhat harder than the ruby, or at least harder to cut.

Hardness may vary with direction; in particular is this noticeable in the case of the gem mineral kyanite which shows a hardness of 5 along the length of the crystal and 7 in directions at right angles to the length. Diamond also shows a variation of hardness with direction but the variation is slight.

<sup>1</sup> Except certain case-hardened types which approach 7 in hardness.

### **Recapitulation**

Cohesion is the force of attraction between the molecules of a substance.

Fracture is the rending asunder of the force of attraction of the molecules (cohesion) when force is applied in any direction which is not a cleavage direction.

Cleavage is a direction of weakness along which, or parallel to which, if force is applied a crystal will split easily with the production of smooth surfaces.

Hardness is the power a substance possesses to resist abrasion

when a fragment of another substance is drawn across it with insufficient pressure to produce cleavage.

***Test Questions***

7. What is the typical type of fracture seen in glass?
8. There are three properties which depend upon cohesion. What are they and which one is only possible in crystals or crystalline material?
9. Give the names of the gemstones which have a hardness of eight or over.

## CHAPTER IV

### SPECIFIC GRAVITY

WHICH weighs more, a pound of lead or a pound of feathers? It is one of the "older" catches, which, absurd as it apparently is, concerns a vital point; relation of weight to volume. For the space taken up by the pound of lead is far smaller than the space taken up by the pound of feathers, even if they were compressed to their smallest bulk. Likewise, the comparatively heavy metal, iron, may be said to weigh more than the light metal aluminium, but if two pounds (by weight) of aluminium and one pound (by weight) of iron are taken, it is obvious that the aluminium would be twice as heavy as the iron. Should, however, equal quantities, by size (such as cubes of 1 in. edge), of these metals be taken, it would then be found that the iron cube would weigh approximately three times as much as the cube of aluminium. Thus, it may be said that the *density* of iron is about three times that of aluminium.

To be of practical value it is necessary to compare the weight of a volume of each substance with the weight of an equal volume of a substance used as a standard. The standard used is pure water at its maximum density, *i.e.*, at 4° C. The value given by this ratio is known as the *specific gravity* (the term generally used for solids) or *relative density* (generally used for liquids). The specific gravity (often termed *density* for shortness) is a physical property of all materials, and as a rule is constant between fairly narrow limits for pure substances. Gemstones may be said to be pure substances and their specific gravities are, with few exceptions, remarkably constant, hence the property may be used as a means for their distinction, one from another.

At first sight it would appear to be an insurmountable difficulty to obtain the volume of an irregular gemstone so as to compare it with an equal volume of water. It is, however, unnecessary to ascertain the volume of the solid (gemstone), by means of calculation, for if the stone is placed in an Eureka can, a metal vessel with an overflow pipe and filled with water, the displaced water passes through the pipe and can be collected and measured. Thus, if the displaced water is measured in cubic centimetres and the stone weighed in grammes, all the necessary figures for computing the density are at once available (*1 cubic centimetre of water weighs 1 gramme*). Easy as this method appears, it does not lend itself to the accuracy required for small bodies, such as gemstones.

Of far greater accuracy is the variously termed *direct weighing method* or *hydrostatic weighing method*, which depends upon the principle, discovered by the Greek philosopher, Archimedes, that a body immersed in a liquid is buoyed up by a force equal to the weight of the liquid it displaces. Therefore, if an object is first weighed in air, and then, when suspended by a thread, in water, it weighs less the second time by an amount equal to the weight of water equal in volume to itself, this weight, divided into the weight of the object, gives the specific gravity.

This method is one of the most important used in gemological science. It requires the use of a delicate balance. There are special balances marketed for the purpose of specific gravity determination, but they do not appear to be widely used. A good chemical or assay balance or diamond scales answers admirably, as it would have the necessary qualification of being capable of weighing to a milligram (0.005 carat). One of the most convenient methods of using a plain chemical balance for specific gravity work is first to prepare a wooden or metal stool, which will straddle the left-hand pan in such a manner that it does not in any way hinder the swing of the balance. On this stool is placed a beaker of water, again ensuring that it clears the pan arms of the balance.

From the hook at the end of the beam, from which is suspended the pan arms, there is placed a loop of fine wire which carries at its lower end a cage, formed of stouter wire, to take the stone. It may be formed, cone shaped, around the sharpened end of a pencil. The cage dips into the water in the beaker so that it is completely covered during a full swing of the balance. On the similar hook over the right-

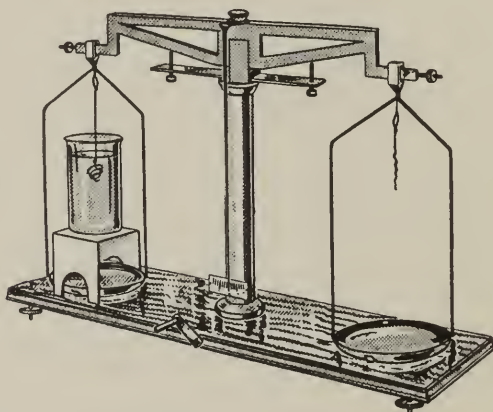


FIG. 10.—Chemical balance arranged for ascertaining the specific gravity of gemstones by the hydrostatic weighing method

hand pan there is placed a piece of wire exactly counterpoising the wire and cage on the left-hand side when dipping into the water (fig. 10). The stone under test may now be weighed in air by placing it in the left-hand pan and adding weights to the right-hand pan.

In practice it is usual to use the metric carat weights, or the gramme weights of the metric system. A set of these weights normally contains the following values: 100, 50, 20, 20, 10, 5, 2, 2, 1, 0.5, 0.2, 0.2, 0.1, 0.05, 0.02, 0.02, 0.01, 0.005,

0.002, 0.002 and 0.001 (carat weights rarely below 0.005), a range from which any combination of weights may be obtained.

To commence weighing it is better to begin by placing a weight in the right-hand pan which is in excess of the object to be weighed. Then, working down through the weights of lower values one at a time, ensuring that the balance pans are lowered every time a weight is changed. The worker removes the weights which are too heavy, returning them to the box, and leaving in the pan the weights which are too light. By this method all the weights are passed through in turn until a correct balance is obtained. *The method, if it can be called a method, of dodging about with the weights, sometimes one of higher value, sometimes one of lower, until some sort of balance is obtained is to be deprecated. It gives neither brilliant results nor speed of working.* The weights in the pan are now removed and added together, giving the weight in air of the stone (X in formula).

The stone is now removed from the left-hand pan and placed in the wire cage which is suspended in the water. It is necessary to ensure that there are no air bubbles adhering to the stone. If some are present they may conveniently be removed with the aid of a small camel-hair paint brush. The stone is now weighed in a similar manner as has been explained before, and the result, which will be of lower value, noted. This is the weight of the stone when immersed in water (Y in formula).

The formula for the determination of specific gravity is:  $\frac{X}{X-Y}$  where X is the weight of the stone in air, Y the weight of the stone when immersed in water. The apparent loss of weight (X - Y) if divided into the weight in air gives the specific gravity.

Example, a red stone weighs 2.063 (carats or grammes) in air, and 1.565 (carats of grammes) when immersed in water, therefore :



Weight of the stone in air	...	2.063	
Weight of the stone in water	...	1.565	
			4.14 = S.G.
Apparent loss of weight	...	0.498	
			1.992
			710
			498
			2120

giving a specific gravity of 4.14, which, on looking-up in a table-book of constants, will be found to be that of almandine garnet.

However, to conform to the definition of specific gravity, it appears necessary to know whether the water was at a temperature of 4° C., and if it was not, how it affects the final determination of S.G. (*S.G. is the abbreviation for specific gravity.*) To correct the work for temperature of the water it is necessary to ascertain the temperature of the water at the time of the experiment and multiply the answer by the density of the water at the temperature found (*densities of water at different temperatures are published as tables in technical books*). With the example given above it will be supposed that the temperature of the water was 14.7° C. (*density of water at 14.7° C. = 0.99917*) so that 4.14 multiplied by 0.99917 will give 4.13, which gives the density of the stone correct to 4° C. In general gem testing this refinement of temperature correction is unnecessary, nor is there any value in carrying on the division sum to more than two places of decimals, for the drag on the wire, due to the surface tension of the water, precludes real accuracy for more than the second place except for large specimens. To avoid this surface tension a liquid such as benzene or toluol may be used in place of water. Should these liquids be used, it is essential that the correction for temperature is made, for the density



of these liquid hydrocarbons is considerably different from that of water and, moreover, varies greatly for changes of temperature.

There is a type of spring balance marketed specially for the purpose of specific gravity determinations of solid bodies. It is known as the Jolly balance. An American production, it works better for large specimens, such as crystals and pieces of rocks.

Also used in America is a special form of torsion balance, known as the Berman Density Balance, which gives more accurate results than does the diamond scales, especially with stones less than two carats in weight. Calculations are made on the Berman Density Balance by the same method used in hydrostatic weighing.

The methods of density determination just discussed suffer from the disadvantage that the weighing and subsequent calculation take some considerable time. Methods which can be most useful, speedy, and capable of extreme accuracy can be carried out by the use of *heavy liquids*. A stone will float in any liquid which has a higher density than itself, sink in one of lower density, and in a liquid of the same density it neither floats nor sinks but remains motionless wherever it is placed (termed *freely suspended*), therefore, if a stone is found to remain freely suspended in a liquid, it is only necessary to find, by some means, the density of the liquid to know that of the stone.

The ideal conditions required for a *heavy liquid* are, a high density and the capability of intimately mixing with another liquid of lower density for the production of a mixture having any density between the limits of the two fluids. There are many liquids which have the necessary conditions in a varying degree and which have been adopted at various times for gem-testing purposes. In the fairly complete list of these liquids which is given below, modern practice has selected three as being the most useful. These three liquids are printed in small capitals.

1. BROMOFORM, a colourless liquid (turning yellow on exposure to sunlight), having a density of 2.9. The density

can be lowered by dilution with benzene or toluol (density = 0.88). Bromoform is useful for stones of low density, such as beryl and quartz.

2. Acetylene tetrabromide. Density = 2.95. May be diluted with benzene or toluol.

3. Sonstadt's solution (a saturated solution of potassium mercuric iodide in water). Density = 3.18. May be diluted with water.

4. Klein's solution (cadmium boro-tungstate in water). Density = 3.28. May be diluted with water.

5. METHYLENE IODIDE ( $\text{CH}_2\text{I}_2$ ). Density = 3.32. May be diluted with benzene or toluol or bromoform.

6. Rohrbach's solution (barium mercuric iodide in water). Density = 3.58. May be diluted with water.

7. Methylene iodide with iodine and iodoform forms a nearly opaque and viscous liquid with a density of 3.6.

8. CLERICI'S SOLUTION (thallium malonate and formate in water). Density = 4.15 at room temperature. May be diluted with water.

9. Retger's salt (thallium silver nitrate) is a solid at ordinary room temperature, and for use must be heated in a water bath to 75° C., when it melts to a yellow liquid having a density of 4.6 and may be reduced to a lower density by dilution with water.

The density of a liquid, in which a stone under test is found to be freely suspended, may be ascertained by several methods. Of these methods, the one necessitating the employment of a *specific gravity bottle* or *pycnometer*, will be discussed first. This method is one of considerable accuracy but its use is mostly confined to work of an exceptional nature for the necessary weighings are time-consuming. The *specific gravity bottle* (fig. 11) is a small glass flask fitted with a ground glass stopper, which is pierced lengthwise by a capillary opening. The flask is generally engraved on the outside with the weight of water it will contain



FIG. 11. —  
The specific gravity  
bottle

at room temperature ( $15^{\circ}$  C.), so that if the flask is first weighed when empty and again when filled with the liquid whose density is to be determined, the difference between the two weights will give the weight of the liquid. The weight of an equal volume of water is known by the value engraved on the flask (*if not so marked, this can be found by weighing the flask when filled with water and subtracting from this weight the weight of the empty flask*). Then by dividing the weight of the water into the weight of the liquid is ascertained the density of that liquid.

*Example*

Weight of water in bottle	50 grammes.
Weight of bottle and liquid	202 grammes.
Weight of bottle ... ..	<u>35 grammes.</u>
Weight of liquid ... ..	167 grammes.

Hence, density =  $\frac{167}{50} = 3.34$  (*correction for temperature as for direct weighing method*).

Therefore a transparent green stone which remained freely suspended in this liquid would have a specific gravity of 3.34, hence would be a peridot. The specific gravity bottle may also be used for determining the density of small gems, the method being as follows: The flask is weighed when empty (A), and then when full of water (B). The flask is then emptied and dried and the stone placed inside the bottle and the whole weighed (C). The bottle, still containing the gem, is then filled with water and again weighed (D). The specific gravity is calculated by the formula:

$$\frac{C - A}{B + C - A - D}$$

The *Westphal balance* is constructed expressly for the determination of the density of liquids and its essential design is that of a modified Roman balance, or butcher's steelyard (fig. 12). At the end of the graduated arm is suspended a sinker which dips into the liquid whose density is required to be known. This sinker, which contains a small ther-

rometer, is so weighted that when it is immersed in water the balance is accurately counterpoised. So that when the sinker is placed in a liquid denser than water it is buoyed up and it is necessary to place weights on the graduated arm to bring the balance again to the counterpoise position. The weights employed are arbitrary, but are all multiples of some standard weight and the density of the liquid can be read directly from the position of the various weights on the

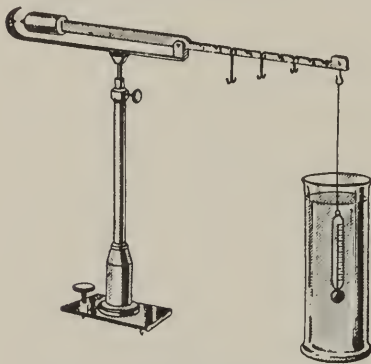


FIG. 12.—The Westphal balance



FIG. 13.—A modification of the Westphal balance

beam. The Westphal balance may be modified to allow it to be used for the direct weighing method. This is carried out by the substitution of the sinker by a pan and clip (fig. 13), and the method of use is as follows: The clip is immersed in water and weights added to the beam until it is counterpoised (A). These weights are then removed, the stone placed in the pan, and weights again added to obtain a counterpoise (B), the clip still remaining in the water. The operation is repeated with the stone enclosed in the clip and immersed in the water (C). Specific gravity is found by the formula:

$$\frac{A - B}{C - B}$$

A method for ascertaining the density of a liquid, while not so accurate as those mentioned previously, is by the use of a suitably graduated hydrometer. A hydrometer of the fixed graduated type is generally made of glass with the base weighted with shot or mercury, and has a narrow stem marked with the density values (fig. 14). When the instrument is immersed in the liquid under test it floats at a definite level, and if the value shown on the graduated stem at the level of the liquid is read, this reading will give the density of the liquid. Fixed hydrometers are usually constructed to cover only a small range of densities, as a wide range would necessitate an inordinately long stem. A number of these instruments, of different ranges, are necessary if a



FIG. 14.—  
The  
hydrometer

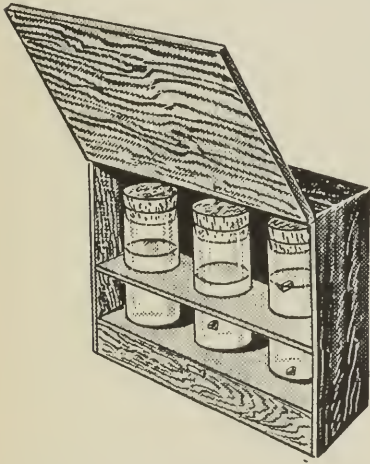


FIG. 15.—Heavy liquid bottles in cabinet

very full range of density is required to be covered.

As the instruments are calibrated at a certain temperature (usually marked on the stem) correction may be required and in using hydrometers, easy and quick as their use may be, care must be taken that they float clear of the sides of the vessel containing the liquid. Likewise, care is necessary to ensure that the reading is taken at the level of the liquid, and not at the top of the

curve of the liquid where it meets the stem (*the meniscus*).  
To distinguish between gemstones it is rarely necessary to use such accurate methods and, with *heavy liquids*, comparative

methods are considerably more useful. If a series of glass tubes, fitted with corks or ground glass stoppers, are obtained and arranged in a wooden box (certain heavy liquids darken on exposure to light), they may be half-filled with heavy liquids that are suitably diluted so as to give a range of densities, Fig. 15. It is unnecessary to be accurate with these densities; for example, if a liquid is made up which will float a quartz (S.G. = 2.65), and in which a beryl (S.G. = 2.7) will sink, the density of the liquid must lie somewhere between 2.65 and 2.7. If a series of tubes are made up to a range of densities, using small gemstones of known species as indicators, or the density "cubes" made by Rayner, it is possible to ascertain, within limits defined by the nearness of the values of the tubes, the approximate S.G. of a suspected stone by placing them in different tubes, one after another, and noting whether the stone sinks or floats. The range and value a series of tubes are made up to is dictated by the worker's own needs, but for the sake of example, a suggested series is given, as follows :

1. Bromoform diluted with toluol to approximate density of 2.5 (*indicators; gypsum = 2.3 and moonstone = 2.57*).
2. Bromoform diluted with toluol to approximate density of 2.7 (*indicators; quartz = 2.65 and calcite = 2.71*).
3. Pure bromoform, density = 2.90 (*bromoform is fairly stable so that no indicators are necessary*).
4. Methylene iodide diluted with toluol to density of 3.1 (*indicator; tourmaline which remains freely suspended*).
5. Pure methylene iodide. Density = 3.32 (*no indicator necessary*).
6. Clerici's solution diluted with water to density of 3.52 (*indicator; small diamond which remains freely suspended*).
7. Clerici's solution diluted with water to approximate density of 3.7 (*indicators; spinel = 3.60 and chrysoberyl = 3.73*).
8. Clerici's solution diluted with water to density of 4.0 (*indicator; synthetic ruby freely suspended*).



If the liquids are unused for some time it will be found that the denser indicator will have floated to the top, due to the evaporation of the toluol (or benzene). This evaporation increases the density of the liquid which has to be re-diluted by the addition of a small quantity of toluol. Care is necessary when testing stones, to ensure that they are wiped when they are removed from a tube of liquid and before being placed in another tube, either of the same type of liquid or in a tube containing a liquid of another composition. It is unwise to immerse in liquids such porous stones such as turquoise, opals and pearls, or, if it is necessary to use heavy liquids for such gems, they should be quickly removed, rinsed in clean benzene and carefully dried.

Ten level teaspoonfuls of common salt dissolved in a tumbler of water produces a solution having a density between the S.G. of amber (1.08) and the S.G. of the common amber substitute, bakelite (1.26), and other plastic imitations, hence, this solution is a useful addition to the *heavy liquids* for the detection of amber. Amber floats on the salt solution

while the imitations sink. It should be noted, however, that this solution will not separate the natural copal resins nor the synthetic resin "polystyrene," which have the same density as true amber.

If a tall glass measure is half-filled with a heavy liquid, and on top of this is gently poured a less dense liquid, but one that is miscible with the first liquid, and left to stand for some time (gentle shaking will assist the process), a column of liquid is formed, by diffusion of the two liquids one with another, which progressively increases in density from top to bottom. This is known as a *diffusion column*. Then supposing three stones of different densities to be gently dropped into the liquid, they would be found to take up stations at different

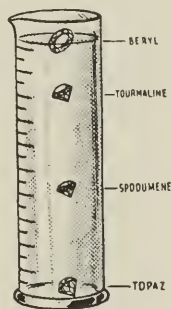


FIG. 16.—A diffusion column with gems in suspension

levels, levels where the density of the liquid matches that of the stones (fig. 16). It is then quite obvious that if a suspected stone is found to float at a point between the levels taken up by two other stones of known specific gravity, the S.G. of the suspected stone must be somewhere between the densities of the stones acting as indicators. While the diffusion column is useful in detecting small differences of specific gravity, it does not compare in usefulness with the tubes of liquids made up to different densities, either for ease of preparation or for convenience of storing.

Below is appended a short list of the average specific gravities of the most important gemstones. The species name is printed first followed by the variety names, where these are important, *e.g.*, ruby and sapphire are merely colour varieties of the species, corundum.

## SPECIFIC GRAVITIES

Opal ... ..	2.1
Feldspar (moonstone) ... ..	2.57
Quartz (rock-crystal, amethyst, citrine) ...	2.65
Beryl (emerald, aquamarine, morganite) ...	2.71
Turquoise ... ..	2.75
Tourmaline ... ..	3.10
Spodumene (kunzite, hiddenite) ... ..	3.18
Peridot ... ..	3.34
Diamond ... ..	3.52
Sphene ... ..	3.53
Topaz ... ..	3.53
Spinel ... ..	3.60
Garnet (hessonite) ... ..	3.61
Chrysoberyl (alexandrite, cat's-eye) ... ..	3.72
Garnet (pyrope) ... ..	3.78
Garnet (demantoid) ... ..	3.84
Corundum (ruby and sapphire) ... ..	4.00
Garnet (almandine) ... ..	4.05
Zircon (low type) ... ..	4.00
Zircon (medium type) ... ..	4.20
Zircon (high type) ... ..	4.69



**Recapitulation**

Specific gravity is the comparison of the weight of a substance with the weight of an equal volume of another substance used as a standard (standard used is water at 4° C. Therefore water equals unity).

Formula for determining density by hydrostatic weighing method:—

$$\frac{X}{X - Y} \times T$$

Where X is the weight of the stone in air, Y is the weight of stone when immersed in water (or whatever liquid used), and T is the density of water (or liquid) at the time of the experiment.

Most useful heavy liquids:—

*Bromoform* ( $\text{CHBr}_3$ )  $d = 2.9$ , dilution with benzene or toluol.

*Methylene iodide* ( $\text{CH}_2\text{I}_2$ )  $d = 3.32$ , dilution with benzene, toluol or bromoform.

*Clerici's solution.* A mixture of thallium malonate ( $\text{CH}_2(\text{COOTl})_2$ ) and thallium formate ( $\text{HCOOTl}$ ),  $d = 4.15$  at room temperature, dilution with water.

**Test Questions**

10. Name three gemstones which will float on pure bromoform.
11. What methods would you use to ascertain the density of a stone 0.5 carat in weight?
12. A yellow crystal is seen to belong to the cubic system. It is found to float on pure methylene iodide and to sink in pure bromoform. What is its species?
13. Name a gemstone which is denser than all the usual heavy liquids.
14. Why are hydrometers rarely made to cover a large range of densities?
15. Is it wise to immerse all gemstones in heavy liquids? Give reasons for your answer.

## CHAPTER V

### LIGHT

TRULY, without light there could be no world as we know it. No beauty of the sea and sky and no sight of the glorious colours of the flowers in the field, or of the beauty of the precious minerals which are termed gems. Light, however, to the student of gemology has a more vital interest even than that of beauty—the value it possesses as a means for gem identification.

What is light? That it is the physical cause of our sensation of sight is obvious, just as we may say that it is simply an effect interpreted by our brain through the medium of the eye and has no real existence, but, of its nature, even with the advanced state of science to-day, we are uncertain.

In the year 1666, Sir Isaac Newton suggested that light was due to streams of infinitesimally small particles projected in all directions in straight lines from the luminous body that gave the light. The particles were supposed to be able to penetrate transparent substances, and when they struck upon the retina of the eye to give the sensation of vision. This was called the *emission* or *corpuscular* theory of light.

While this theory was then regarded as quite adequate, as time went on it was found to be insufficient to account for many of the phenomena of light, and was superseded by the *wave* or *undulatory* theory. A clear statement of this theory was given by the Dutch physicist, Huyghens, in 1678, in which it is supposed that light consists of some kind of waves coming from a luminous source. For light to have a wave form it seems essential for it to proceed through some sort of medium (*the term "medium" is used to express any substance through which light passes, and may refer to either solids,*

*liquids or gases*). When the light source is that of a candle, gas flame or electric light, the atmosphere may appear to be that medium, but, if we consider that great natural producer of light energy, the sun, the position is different. The sun is 93,000,000 miles away and the earth's atmosphere extends to some 200 to 300 miles above its surface, beyond which there is space, containing, as far as we know, nothing but a few atoms per cubic yard.

In order to support the theory there must be some kind of medium to transfer the wave motion, hence, some scientists assume the existence of a hypothetical medium which is elastic and weightless and is termed *the ether* which pervades all material bodies as well.

This theory supposes that wave motion is propagated by successive parts of the ether setting each other in motion by mutually attractive forces. This idea was later modified by the work of James Clerk Maxwell, who suggested that the vibrations were due to periodic alterations in the electrical and magnetic condition of the ether. This is known as the *electro-magnetic theory*.

The conception of light energy was again altered during recent years by a suggestion that the original corpuscular theory was set aside too hastily, and that the various phenomena in connection with light cannot be wholly explained on the basis of the wave theory alone. However, for the study of gems, the wave theory satisfactorily explains all the light phenomena which it is necessary to deal with.

Unlike the waves which are produced when a stone is thrown into water, causing the water surface to vibrate in paths at right angles to the surface only, termed *transverse* waves, the waves of light move in all possible directions at right angles to the direction of travel, termed *spherical* waves. The length of these waves is the nearest distance measured

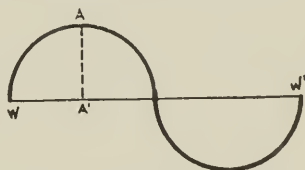


FIG. 17.—Wave form.  $W-W'$  = wave-length.  $A-A'$  = amplitude

between two particles on the wave surface in identically the same position and travelling in the same direction. The intensity of the energy (light) is determined by the amplitude (fig. 17).

White light, or as it is often termed *mixed* light, is composed of a mixture of red, orange, yellow, green, blue, indigo and violet light rays, each of which have a different wave-length. Therefore, the colour of light varies with, and depends upon, the wave-length. Red waves have the longest wave-length and this diminishes through orange, yellow, green, blue to violet, which has the least wave-length and about half the length of the red rays. When light is produced

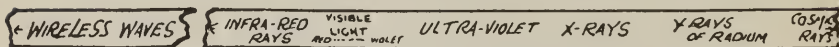


FIG. 18.—The electro-magnetic spectrum

which has one wave-length only it is then termed *monochromatic* light.

When energy has a shorter wave-length than the violet rays, and is therefore invisible, they are termed *ultra-violet* rays, while below the ultra-violet there are those radiations, discovered by Röntgen in 1895, known as X-rays. Still shorter rays are those emitted by radium and termed *gamma* rays and the shortest yet known to science are the *cosmic* rays now being investigated by scientists all the world over. Similarly, at the other end of the scale there are those invisible rays of longer wave-length than the red rays. They are termed the *infra-red* rays and are, in fact, heat rays. Finally, far beyond these heat rays come the rays with the comparatively long wave-lengths of anything from a few metres to something like 2,000 metres. They are the so-called *Herzian* waves, more familiar to us as “wireless.” The whole range of these waves produces what is known as the *electro-magnetic spectrum*. In the centre of this spectrum lies that very small octave, the range which affects our eyes, visible light (fig. 18).

The lengths of light waves are so small that measurement

by ordinary standards, such as centimetres, is most inconvenient, for instance, the wave-length of the yellow ray (the  $D_1$  line of sodium) is 0.0005896 centimetre. It becomes more understandable if it is expressed as a multiple of a ten-millionth part of a millimetre, a unit advocated by A. J. Angstrom in 1868, and universally adopted. The wave-length of the yellow ray is then 5,896. *Angstrom units* or *angstroms* (generally written A).

All the qualities which go to make up the beauty of precious stones are directly due to the powerful influences which they exert upon reflected and transmitted light. The first quality to be considered is *transparency*, which is the ability of a substance to transmit light. It is roughly divided into degrees of transparency as follows:—

TRANSPARENT.—An object viewed through them shows outlines clear and distinct; *e.g.*, most gemstones, such as diamond, spinel, emerald, etc.

SEMI-TRANSPARENT.—Object would be blurred, but considerable light can penetrate the stone; *e.g.*, white carnelian.

TRANSLUCENT.—Some light passes through but no object can be seen; *e.g.*, opal.

SEMI-TRANSLUCENT.—Light only transmitted well through the edges; *e.g.*, chrysoprase.

OPAQUE.—No light passes through; *e.g.*, turquoise.

The above description is considered to refer to specimens of ordinary thickness, for even the opaque turquoise is translucent if ground to thin sections. Colour will also diminish the effect as will feathers, flaws and fibrous inclusions.

Before considering the other qualities of gemstones in relation to light, it will be as well to discuss the action of light rays when they impinge upon a medium, or from one medium into another.

When a ray of light impinges upon a mirror or other polished surface (say, that of a gemstone), the ray is turned back at the point of incidence (*the point where the ray strikes the surface of the two media in contact*) in a direction opposite to

the direction in which it arrives, and at a similar angle, *i.e.*, similarly to the manner in which a ball returns when it is thrown at an angle against a wall. This may be explained better by a geometrical example, as fig. 19, PM is a plane reflecting surface. IO a ray of light (the *incident ray*) falling on the mirror at O. O is called the point of incidence. OR is the ray reflected (returned) from the mirror. NO is termed the *normal at the point of incidence* (the *normal* in optics is an imaginary line at right angles to the surface separating the two media at the point where a light ray strikes the separating surface. It is the base line from which all angles made by

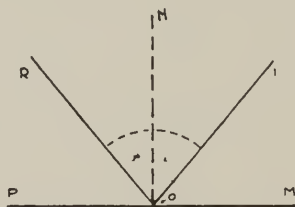


FIG. 19.—Reflection of light

light rays are measured). The angle ION is the angle of incidence (*i*). The angle NOR is the angle of reflection (*r*). The incident ray, IO, the normal, NO, and the reflected ray all lie in the same plane.

The LAWS OF REFLECTION are expressed as follows:—

- (1) The angle of incidence (*i*) is equal to the angle of reflection (*r*).
- (2) The incident ray, the normal and the reflected ray are all in the same plane.

Reflection effects are very important in cut gem stones and have a great deal to do with such properties as lustre and sheen and such effects as asterism (star-stones) and chatoyancy (cats'-eyes).

When a ray of light *enters* a stone (or any medium) in an oblique direction the ray, instead of travelling through the

stone in a direct line (that is the straight continuation of the incident ray) is found to alter its course. This bending of the light rays is termed *refraction* and is responsible for such commonly observed facts as the apparent bending of a straight stick when it is partially immersed in water.

For refraction to take place it is necessary for the light to be travelling through media of different optical densities (*not* to be confused with “density” or “specific gravity”). When a ray of light travels from air, an optically rare medium,

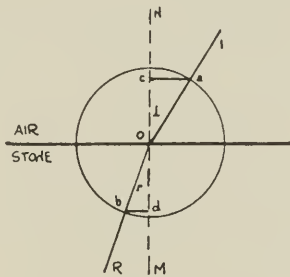


FIG. 20.—Refraction of light

into a gemstone, an optically denser medium, the refracted ray is bent towards, or nearer to, the normal.

Expressed geometrically (fig. 20) IO is the incident ray, OR the refracted ray, and NM the normal at the point of incidence. It will be seen at once that the angle of incidence ( $i$ ) ION, is greater than the angle of refraction ( $r$ ) MOR, and experiment has shown that any increase, or decrease, in the angle of incidence causes an increase, or decrease, in the angle of refraction, and that this variation is in some definite proportion.

The LAWS OF REFRACTION, attributed to the physicist Snell in the seventeenth century and known as SNELL'S LAW, are expressed as follows:—

- (1) The sine of the angle of incidence bears to the sine of the angle of refraction a definite ratio which depends



only upon the two media in contact and the nature (colour) of the light, *i.e.*:—

$$\frac{\text{Sine } i}{\text{Sine } r} = \text{a constant.}$$

- (2) The incident ray, the normal at the point of incidence and the refracted ray are all in the same plane.

In a right-angled triangle the sine of an angle is the ratio between the side opposite the angle and the hypotenuse (the *hypotenuse* is the side of a right-angled triangle opposite the right angle); hence (fig. 20) if a circle is described with centre at the point of incidence O, and with any radius which cuts the incident and refracted rays at *a* and *b* respectively, perpendiculars *ac* and *bd* dropped on to the normal produce right-angled triangles. Therefore, the ratio of the side *bd* and the hypotenuse *bO* gives the sine of the angle of incidence (the angle *i*), and likewise ratio of the sides *ac* and *aO* give the sine of the angle of refraction (the angle *r*).

From the laws of refraction it will be seen that:—

$$\frac{\text{Sine angle of incidence}}{\text{Sine angle of refraction}} = \frac{\text{Sine } i}{\text{Sine } r} = \text{a constant}$$

a constant, which, when a ray of light travels from air to another medium, is termed the *refractive index* of that medium and is a measure of its refractive power. Refractive index (usually termed R.I.) is constant for the same medium, but differs for different substances, *e.g.*, the R.I. of water differs from that of, say, Vaseline. However, water always has the same index of refraction and so does all Vaseline. Hence, the constant forms a valuable factor for the discrimination of gem materials.

When dealing with specific gravity, we saw that water is used as the standard or unity. The standard used for refractive index is air (strictly speaking it should be a vacuum, but the difference between air and a vacuum is so small that it is



negligible); therefore, the refractive index of air is reckoned as 1. Gemstones are optically denser than air so that their index of refraction is greater than 1. (*Methods whereby the constant of refractive index can be used to differentiate between gems and counterfeits will be discussed in a later lesson.*)

Light is reversible, that is, it may travel from the denser medium to the rarer medium, *e.g.*, from a gemstone into air. Therefore, it will be obvious that the incident ray, now in denser medium, will make a smaller angle with the normal than does the refracted ray which is now in the rarer medium. Considering the case more thoroughly, we will realize that as the angle of refraction increases in ratio with increase of

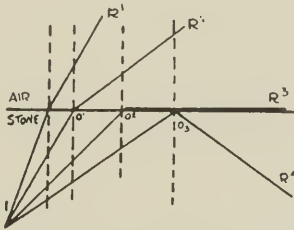


FIG. 21.—Total internal reflection of light

the angle of incidence, there will become an angle of incidence where the refracted ray is at an angle of  $90^\circ$  to the normal. That is, the refracted ray just grazes the surface separating the two media ( $R_3$ , fig. 21). Any further increase of the angle of incidence causes the ray to turn back into the first, denser, medium ( $R_4$ , fig. 21), where it obeys the laws of reflection and *not* the law of refraction. This phenomenon is termed *total internal reflection of light*. The angle of incidence which gives an angle of refraction of  $90^\circ$  is termed the *critical angle* and is usually denoted by the Greek letter theta  $\theta$ . The critical angle determines the beginning of total internal reflection.

Total internal reflection is a property which is made use of in much of the optical apparatus used to-day; examples

which may be cited are the various forms of totally reflecting prisms incorporated in such apparatus as submarine periscopes and in prismatic binoculars.

The value of the critical angle may be expressed by the formula:—

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

where  $i$  is the critical angle and  $n$  the index of refraction, hence, it follows that the higher the refractive index the smaller the critical angle. That is, more light will be totally

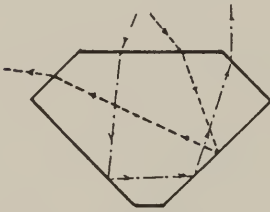


FIG. 22.—Path of light rays in a diamond

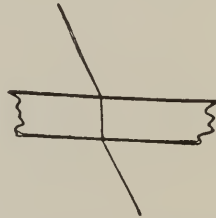


FIG. 23.—Path of light rays through a parallel-sided glass plate

reflected in a medium of high refraction, and this explains the brilliancy of the diamond. Most of the light rays which enter the diamond from the front are totally reflected from the back facets and out again through those at the front (fig. 22).

When a beam of white light is passed through a transparent medium with parallel sides, such as a glass plate, the emergent ray is found to be parallel to the incident ray although often laterally displaced (fig. 23). When, however, a beam of white light is passed through a transparent medium with two inclined faces, such as a glass prism, the ray of white light is resolved into the familiar colours of the rainbow (fig. 24). This resolution is due to the fact that each colour is bent, or deviated, a different amount; that is, the

refractive index of a medium differs for each ray and increases regularly with decrease of wave-length.

Thus, the prism analyses the beam of white light and arranges the various coloured rays according to their wave-length. The longer waves (red light) are least deviated, while the shorter waves (violet light) are most bent, or are, as it is termed, more *refrangible*. This separation of the rainbow colours, first observed by Newton, is termed *dispersion* and determines the effect known as "fire."

Dispersion or "fire" may be defined as the play of prismatic colours and is strongest in such stones as diamond,

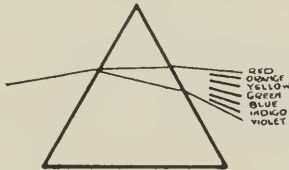


FIG. 24.—Dispersion of light in a glass prism

demantoid and hessonite garnet, sphene and zircon. It is best seen in diamond and colourless zircon, for in the others the effect is masked by the colour of the stone.

The amount of dispersion is measured by the difference between the refractive index for the red ray and the refractive index of the violet ray, but in practice it is usual to take what is known as the B and G lines of the spectrum (*spectrum* is the name applied to the spread of rainbow colours) which have wave-lengths of 6,867 angstroms and 4,308 angstroms, respectively. The dispersion of diamond for the different coloured rays is as follows:—

Red	(6,870 Å)	= 2.407 n
Yellow	(5,890 Å)	= 2.417 n
Green	(5,270 Å)	= 2.427 n
Violet	(3,970 Å)	= 2.465 n
		(n = refractive index)

This gives the amount of the dispersion between the red and the violet rays of 0.058. Between the B and G lines the dispersion of diamond is 0.045.

The *fundamental* colour of a medium (gemstone) is caused by the absorption of certain wave-lengths (colours) from the white light falling upon it, thus causing the residual colours (those *not* absorbed) to give a colour to the medium. In opaque stones this absorption takes place at or near the surface, and in transparent stones the absorption takes place when the light is passing through the stone. Light passing through a ruby has the orange, yellow, green and violet absorbed from the spectrum; hence, the red and some blue are transmitted, which together give the typical ruby colour. This effect causing colour is termed *selective absorption of light*.

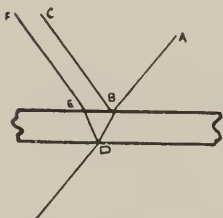


FIG. 25.—Interference of light at a thin film

Colour may also be produced by what is known as *interference*. If a ray of light impinges on a thin film, such as a soap bubble, AB in fig. 25, part of the ray is reflected along BC and part BD refracted into the medium (thin film), where it is reflected along DE and out along EF. BC and EF are parallel and close together, but EF will be retarded owing to its longer passage along BDE. Hence, if the incident light is white some of the wave-lengths will be half a wave-length different. That is, out of phase (the crest of one wave will fill the trough of one in the other set, thus destroying light of that colour) leaving the complementary spectrum colours visible to the eye, colours which differ according to the angle at which the surface is viewed. This effect is the cause of the colours of the opal, opal being a solidified jelly containing many thin cracks, which are filled with material of a slightly differing refractive index.

The appearance of a stone in reflected light is termed its *lustre* and is mainly a function of its R.I., its structure and

transparency. While in no way is it suggested to be related with hardness, hardness must have some influence in determining the polish, and polish does have some influence on lustre. Lustre is known as *adamantine* in those stones of high R.I., such as diamond and zircon, while most gemstones have a lustre described as *vitreous* or glass like; *resinous* is the type shown by amber, some opals and hessonite garnet. *Silky* lustre is seen in fibrous stones, such as satin-spar, while *pearly* is typical of mother-of-pearl. *Dull* lustre is that seen on many opaque stones, as turquoise, while *greasy* is the type seen in soap-stone. Certain opaque minerals, such as marcasite and pyrites, gold and silver, etc., have a *metallic* lustre.

In contradistinction to lustre, *sheen* is due to reflection from within the stone and is termed *opalescence* when the reflections consist of milky or pearly reflections, e.g., moon-stone. The cat's-eye effect, known as *chatoyancy*, is due to reflections from parallel fibrous cavities within the stone, which, when the stone is cut en cabochon (that is with a dome-shaped top), show a single wavy band of light which moves as the stone is turned. The band of light is at right angles to the direction of the fibres and may be likened to the band of light seen on a reel of silk. Should the fibres run in three directions, such as in some ruby and sapphire, and occasionally in rose quartz, where the fibres run in three directions parallel to the lateral axes of the hexagonal system a six-rayed star of light is produced provided the stone is cut with the base in the same plane as the lateral axes. This effect is termed *asterism*, and the stones are known as star-stones.

In all the phenomena that have so far been discussed, light has been assumed to travel through all media as one ray. This is not always so. In material in which light does travel as one ray, the material is said to be *singly refracting* or *isotropic*. Such materials are amorphous substances, as glasses, resins and all liquids; and all crystals of the cubic system. In the other crystal systems the incident ray is split into two rays which take different paths within the stone. That is, they have differing refractive indices. Such material is termed

*doubly refractive* or *anisotropic*, and the effect is well seen in the variety of calcium carbonate known as *Iceland spar*. Print viewed through the spar is seen to be doubled.

In doubly refractive stones there are either one or two directions parallel to which light suffers no double refraction; these are termed *optic axes*, and are perhaps better defined as directions of single refraction in a doubly refractive stone. The tetragonal and hexagonal systems have one optic axis, which is parallel to the principal crystal axis. Crystals of these systems are said to be *uniaxial*. Crystals of the other three systems, the rhombic, monoclinic and triclinic systems, have two optic axes, which do not necessarily show a relation to the crystal axes; hence, these crystals are termed *biaxial*.

In uniaxial stones one of the rays has a refractive index which is constant and independent of the direction of the ray. It obeys the ordinary laws of refraction and is termed the *ordinary* ray, and is usually denoted by the letter *o*, or by the Greek letter *omega* =  $\omega$ . The other ray, termed the *extraordinary* ray, has a refractive index which varies from that of the ordinary ray to a second limiting value. The extraordinary ray is denoted by the letter *e*, or by the Greek letter *epsilon* =  $\epsilon$ . If the extraordinary ray has an index of refraction greater than that for the ordinary ray, the *sign* of double refraction is said to be *positive*, if less, *negative*.

In biaxial stones there are still only two rays travelling in any one direction, but there are three critical values for the refractive index. One corresponding to rays vibrating parallel to the line bisecting the acute angle between the optic axes (*acute bisectrix*); one corresponding to rays vibrating parallel to the line bisecting the obtuse angle between the optic axes (*obtuse bisectrix*); and the other, an intermediate index, corresponding to rays in which the vibration is at right angles to the other two. These three indices are denoted by  $\alpha$  (the smallest),  $\beta$  (the intermediate), and  $\gamma$  (the largest). When the greatest index (*gamma* =  $\gamma$ ) is the acute bisectrix, the stone is said to be positive in sign. When the least index (*alpha* =  $\alpha$ ) is the acute bisectrix the sign is negative. The sign of biaxial

stones may also be shown by the difference in magnitude of the three indices of refraction. When the intermediate index (*beta* =  $\beta$ ) is nearer to  $\alpha$  than it is to  $\gamma$ , the stone is positive, and when nearer to  $\gamma$  than to  $\alpha$ , the stone is negative.

*Example.*

Topaz	$\alpha = 1.607,$	$\beta = 1.610,$	$\gamma = 1.618.$
Epidote	$= 1.730,$	$= 1.754,$	$= 1.768.$

Therefore, topaz is positive and epidote is negative.

*Birefringence* is the term used for the strength of the double refraction, that is, the difference between the indices  $\omega$  and  $\epsilon$  in uniaxial stones and between  $\alpha$  and  $\gamma$  in biaxial stones.

*Example.*

Quartz	$\epsilon. = 1.553$	$\omega = 1.544$	( <i>birefringence</i> = .009)
Topaz	$\gamma = 1.618,$	$\alpha = 1.607$	( <i>birefringence</i> = .011)

In gemstones with large birefringence, such as peridot (0.038), zircon (0.059), the double refraction is apparent by the doubling of the edges of the back facets when viewed through the stone (provided the view is not taken along a direction of single refraction, an optic axis). This test is useful with colourless zircon, which sometimes simulates diamond (diamond is a cubic mineral and hence is singly refractive).

Previously it has been stated that a ray of light vibrates in all directions at right angles to the direction of travel. While this is true for light rays reaching the eye from a light source, when the ray enters a doubly refractive stone and is split into two rays, the vibrations take place in each ray only in one definite direction in the plane at right angles to the direction of travel. This is termed *plane polarized* light, or simply *polarized* light. The two rays in doubly refractive stones are plane polarized in directions at right angles to each other. This effect has a very definite use in gem testing and will be dealt with again when discussing methods for the production of light having this quality.



### **Recapitulation**

A MEDIUM is the name applied to any substance, either solid, liquid or gaseous, through which light passes.

The ether is the hypothetical fluid supposed to pervade all space and material bodies and the medium by which light waves are transferred.

White, or mixed, light is light composed of all colours of the spectrum.

Monochromatic light is light of one wave-length (colour) only.

Transparency is the ability of a substance to transmit light and may be of varying quality.

Ångström units are units for the measurement of the short wave-lengths of light: 1 Ångström = 0.000,001 mm.

Laws of reflection state that the angle formed by the incident ray and the normal at the point of incidence is equal to that formed by the normal at the point of incidence and the reflected ray, all of which are in the same plane.

Laws of refraction (Snell's law).

1. The sine of the angle of incidence bears to the sine of the angle of refraction a definite ratio which depends only upon the two media in contact and the nature (colour) of the light.

2. The incident ray, the normal at the point of incidence and the refracted ray are all in the same plane.

The critical angle of total reflection is obtained when a ray of light passing from an optically denser medium to an optically rarer medium has an angle of incidence which will produce an angle of refraction of  $90^\circ$ , that is the refracted ray first grazes the surface separating the two media.

Total internal reflection of light is obtained when the incident ray has an angle greater than that which will produce the critical angle. The ray cannot then leave the first medium and is reflected back into it. It thus obeys the laws of reflection and not the laws of refraction.

Dispersion is the power of a transparent medium to separate the spectrum colours.

The fundamental colour of a medium is caused by the quenching by absorption of certain wave-lengths (colours) from the mixed light falling on, or passing through it, the colours not absorbed combining and thus giving a colour to the medium. This effect is termed the selective absorption of light.

Interference of light will cause colour by the quenching of certain wave-lengths when two sets of waves running closely parallel to one another are out of phase and thus either amplify or destroy each other.

Lustre is due to surface effects and is mainly a function of the R.I., the structure and the transparency.

Sheen is due to reflections from within the medium.

Chatoyancy and asterism are due to reflections from minute canals within the stone. When there is one set of parallel canals



the effect is one line of light at right angles to them (chatoyancy = cat's-eye) and when there are three sets of canals at  $120^\circ$  the three rays produced give a star (six-rayed) effect known as asterism (star-stones).

Isotropic material is singly refractive to light, that is light passes through as one ray.

Anisotropic material is doubly refractive to light and a ray of light which passes through the material is split into two rays.

An optic axis is a direction of single refraction in a doubly refractive crystal.

A uniaxial crystal has one optic axis.

A biaxial crystal has two optic axes.

Birefringence is the term used to describe the amount of double refraction and is measured by the difference between the highest and lowest readings of refractive indices of doubly refractive stones.

### **Test Questions**

16. The wave-length of a ray of light is given as  $3620 \text{ \AA}$ ngströms. Where in the electro-magnetic spectrum would you expect to find this ray?

17. What is the fundamental difference between lustre and sheen?

18. A ray of monochromatic yellow light impinges on a ruby. What colour will the stone appear to the eye, and why?

19. State the amount of birefringence of (a) Topaz, (b) Diamond.

20. What is "fire"?

21. A ray of light passing from a denser to a rarer medium has its refracted ray at  $90^\circ$  to the normal. What is this angle of incidence termed?

## CHAPTER VI

### MEASUREMENT OF REFRACTIVE INDEX

IT will be recalled that in the last chapter, refractive index was stated to be a *constant*, and that it forms a valuable testing factor. How, then, may this constant be measured in order to be of use for differentiating between gemstones? Actually there are several methods whereby this may be accomplished, all of which have, in general, some limit to their usefulness. In the discussion of the different methods which follows no attempt has been made to group them in chronological order, but simply in order of suggested usefulness.

Of prime importance to the gemologist is the method whereby use is made of a special optical instrument termed a *refractometer*, or, as it is sometimes called, a *total reflectometer*.

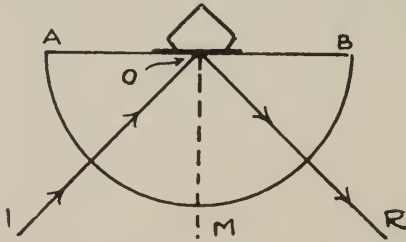


FIG. 26.—Dense glass hemisphere of a refractometer

These instruments measure the critical angle of total reflection, or as is more usual in the ordinary commercial type of instruments, show on a scale calibrated in indices of refraction the shadow edge of this angle.

The essential feature of the instrument is a hemisphere (or in one make, a prism) of, usually, a very dense and highly refractive glass. Fig. 26 represents a section through such a

glass upon which is resting the stone under test (*which must have a refractive index less than that of the glass*). The ray IO passes through the dense glass and strikes the surface AB at the critical angle IOM for the stone and the glass. This ray IO will then be totally reflected and, hence, returned along OR. All the rays penetrating the dense glass between A and I will be totally reflected through the area B—R, which must be in consequence much lighter than the area R—M, because all rays entering the dense glass between I and M do so at an angle less than the critical angle and, therefore, are refracted out and lost through the stone. The position of the bounding edge at R, between the comparatively light and the comparatively dark areas, is a measure of the critical angle of the two media (dense glass and stone) in contact. Assuming that, and it is obvious that it would be in the case of an instrument, the same dense glass is used, any stone having, say, an R.I. of 1.72, will have the shadow edge at a different position from that of a stone with an R.I. of 1.45. If, then, a lens system and eyepiece, complete with scale, arranged so that the shadow edge can be read, is placed in conjunction with the dense glass we have, in fact, a refractometer (see fig. 29).

So far it has been comparatively plain sailing, but, there are some special factors which have not yet been considered, and must be dealt with before going on to the types of instruments available. These are, in general, limiting factors. That is, they preclude the ability of the instrument being used to read indices of high refraction. As should be now quite clear, to obtain total internal reflections it is necessary for the light ray to be travelling from an optically denser medium to one which is optically rarer, hence, any gem stone which has a higher R.I. than the dense glass hemisphere or prism will not return the rays back into the glass by total reflection, but will allow the light to go out through the stone, therefore the scale will be uniformly dark. There have been constructed special types of refractometers made with dense "glasses" of zinc blende and diamond (R.I.'s, 2.37 and

2.42 respectively). The indices for the dense optical glasses used in the ordinary instruments will be given for each instrument as it is discussed; however, in no case does it exceed 1.90.

The second point to consider is that when a clean stone is placed on a clean dense glass of a refractometer a film of air remains between them and prevents *optical contact*. To displace this film a liquid, which will *wet* the glass and the stone, has to be placed between them. This liquid, of necessity, has to have a higher index of refraction than the stone under test, and it is the difficulty of the preparation of such liquids which causes the second limiting factor. There are two qualities necessary for such a liquid—a high index of refraction and the fact that it will *wet* both stone and dense glass. A list of liquids suitable, in varying degree, for use as a contact liquid is now appended.

1. MONOBROMONAPHTHALENE, R.I. = 1.66 (*too low for general use*).
2. METHYLENE IODIDE, R.I. = 1.74 (*no use for corundum gems*).
3. METHYLENE IODIDE, with dissolved SULPHUR, R.I. = 1.79.
4. METHYLENE IODIDE with SULPHUR and  $C_2I_4$ , R.I. = 1.81.
5. PHENYLDI-IODOARSINE, R.I. = 1.85. A poisonous, blistering fluid.
6. WEST'S SOLUTION (eight parts of yellow phosphorus with one part of methylene iodide and one part of recrystallized sulphur), R.I. = 2.05. Spontaneously inflammable unless carefully handled.
7. SELENIUM BROMIDE with a drop of the 1.81 (No. 4) liquid gives readings up to 1.95. Selenium bromide is a dark fluid with a very high refractive index. This fluid, which dissociates upon contact with the air, can be made by the direct reaction between selenium and bromine under concentrated sulphuric acid. It is mixed with the other liquid, which lowers its R.I., in order to give it the necessary "wetting" quality.

It will now be apparent that these two limiting factors taken in conjunction, preclude a reading being taken for diamond. On the usual instruments, which combine a glass hemisphere and "normal" liquids (normal liquids are those numbered 3, 4 and 5 in the list) the gems zircon, sphene and demantoid garnet will only give a *negative* reading, that is, the whole of the scale, up to the edge given by the liquid, appears dark. It must also be pointed out that the specimen under test must have a flat polished facet, hence, the refractometer is of no use for the testing of gems cut en cabochon.

When a stone, such as a spinel, is in position on the dense glass of a refractometer, with a suitable contact liquid between the stone and the glass, and the scale is viewed through the eyepiece, the observer sees the lower half (that is the part of the scale with lower readings up to 1.72) dark, and the higher readings comparatively light. The shadow edge of reading 1.72 is the reading for the stone, and if a careful observation is made it will be seen that there is another edge higher in the scale due to the contact liquid used. Turning again to the shadow edge at 1.72 (for spinel) it will be seen that this edge is in reality a small spectrum in which the red end is in the bright portion of the field and the violet merges into the dark part. In making this statement it is assumed that, as in ordinary general testing it would, the refractometer is used in daylight or ordinary artificial light. The coloured edge is due to the relative dispersions of the stone and the glass. Refractometer glasses have a very high dispersion. If the glass hemisphere and the stone under test had similar dispersions the shadow edge would not be coloured, and one type of instrument has been constructed with a "glass" which will do this. It will be discussed later. However, a shadow edge which is sharp and not coloured may be obtained by the use of *monochromatic light*, which, as has been mentioned in the chapter on "Light," is light of one wave-length (colour) only. The standard monochromatic light for refractometer use is the yellow light of sodium. The majority of the

figures given for refractive indices are for the yellow ray and also all refractometers are calibrated on this ray. Sodium light can be easily obtained by burning in the hot part of a bunsen flame any compound containing sodium, such as common salt ( $\text{NaCl}$ ) or sodium carbonate ( $\text{Na}_2\text{CO}_3$ ), which is perhaps better known as washing soda. An ordinary spirit flame can be used to produce the light by similar means, but for the finest results there is nothing to beat the sodium discharge lamp for brilliant production of sodium light. These lamps are somewhat expensive.

So far, singly refractive media alone have been discussed. Doubly refractive stones, when examined on a refractometer, show not *one* shadow edge but *two* such edges, whose actual position will vary according to the orientation of the stone. On the stone being carefully rotated on the dense glass it will be seen that in certain positions the edges attain maximum and minimum positions. These two readings show the minimum and maximum indices for the stone, and if the figure for the minimum reading is subtracted from the figure of the maximum reading the difference is the amount of double refraction (*birefringence*) of the stone. It must be remembered that all singly refractive stones can only show a single shadow edge and if two edges are seen the stone must be doubly refractive. With stones of weak birefringence it is practically impossible to detect the two edges when white light is used and monochromatic light is then a necessity. The *amount* of double refraction is often of great value in determining between stones of similar refractive indices, care should be taken, however, not to read the edge due to the contact liquid for the higher edge of a stone.

An alternative method whereby the existence of double refraction may be determined on a refractometer is by placing over the eyepiece a nicol prism or other apparatus arranged for the production of plane polarized light. The rays corresponding to the two refractive indices in a doubly refracting stone are vibrating at right angles to one another, the nicol prism only allows light to pass which is vibrating parallel to

a certain direction, hence, by turning the nicol prism to the correct position only the shadow edge due to one ray can be seen, and on rotating the prism through  $90^\circ$ , the other ray can be seen. If the stone is singly refracting there will be no change in reading however the prism is turned, whereas, if the stone is doubly refracting two different readings, a minimum and maximum, are obtained when the prism is turned through a right angle.

To use the refractometer, the instrument should be placed in a position where light from a window or table lamp can enter the instrument. A drop of the highly refractive contact liquid is placed on the centre of the dense glass, which should have been wiped clean with a piece of clean blotting paper. The stone, after being cleaned also (a clean stone is a necessity), is now placed with its table facet down on the dense glass and liquid. The scale is then viewed through the eyepiece. If the scale is not in focus, this may be corrected by the adjustment of the eyepiece. As before mentioned the scale will be seen to be part dark, and part light. Watching the most prominent shadow edge, that of the stone (the other edge, due to the liquid, is weak, and is nearly at the end of the scale), the stone is rotated to see if there is any separation of the edge into two, and, if so, to their maximum separation. Monochromatic light is in all probability necessary if the amount of double refraction is small. Fig. 32 shows the scale of a Tully instrument as it would appear when (*a*) a spinel, (*b*) a topaz, (*c*) a tourmaline is the stone being tested.

The BERTRAND REFRACTOMETER was the first instrument to be produced using the principle of total reflection and embodying a fixed scale (other instruments made on this principle had rotational parts for measuring the critical angle). This instrument was devised by Professor E. Bertrand, in 1885. In appearance it was a short tube, as the illustration (fig. 27), which is drawn from memory, shows. The dense glass being fitted into the end of the tube at an angle. The other end held the eyepiece. Through lack of compensation



of the optical properties of the glass sphere readings were neither good nor accurate.

The HERBERT SMITH REFRACTOMETER was first brought out in 1905, and was designed by Dr. G. F. Herbert Smith.



FIG. 27.—The Bertrand refractometer

The instrument was a modified Bertrand, modified to correct the optical system, and like the Bertrand had a fixed scale. Also, like Bertrand's instrument, the scale was not calibrated in indices of refraction but just in a series of equal spaced and numbered divisions, each instrument being separately cali-

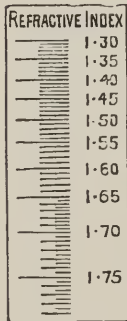


FIG. 28.—The Herbert Smith refractometer with the scale

brated. A card supplied with the instrument had a written table showing what each scale number of that particular instrument represented in terms of R.I. About 1907, the Herbert Smith refractometer was re-designed to its present form complete with a scale calibrated directly in terms of refractive indices (fig. 28). It is essentially a hand instrument fitted with a sliced hemisphere of dense glass which will allow



readings to be taken up to the limit of the scale, which is 1.790. On this instrument no cover is fitted to keep light away from

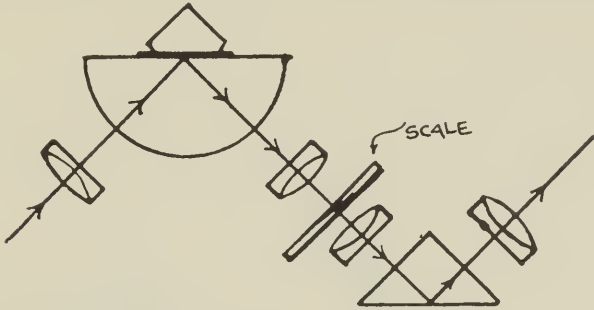


FIG. 29.—The optical system of the Herbert Smith refractometer

the top of the stone and dense glass when readings are being taken, it being intended that the hand used to rotate the

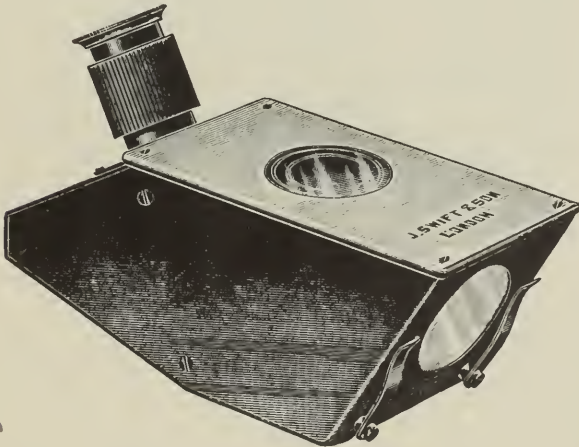


FIG. 30.—The Swift refractometer

stone should perform this duty. Fig. 29 shows the optical arrangement of the Herbert Smith instrument. It is sug-

gested that the best way to use the instrument is to place the refractometer on a book before a piece of white matt paper, such as blotting paper, the whole lay-out being placed in front of a table lamp so arranged that the light is reflected up and into the instrument.

The SWIFT REFRACTOMETER (fig. 30) is of similar design to the Herbert Smith instrument. Its build is slightly heavier than that of the Smith, and a slight variation of the optical system appears to produce a more brilliant scale, which reads

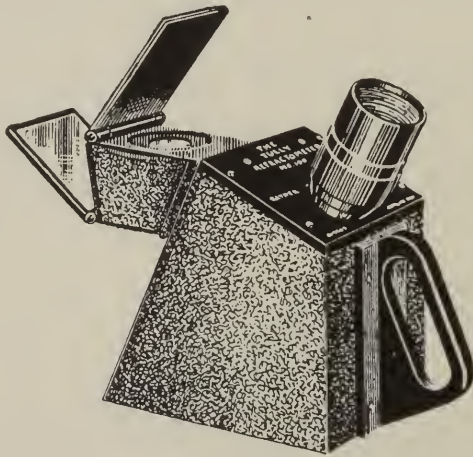


FIG. 31.—The Tully refractometer

to 1.790, with consequent greater ease of reading, especially on the lower numbers.

The TULLY REFRACTOMETER was the first instrument which may be said to have broken away from tradition in design. A product of the years after the Great War, it was designed in 1925 by the late Bristow G. Tully in conjunction with Mr. J. Pike, the technical expert to Messrs. Rayner & Keeler, Ltd. Essentially a table instrument, fig. 31, its large and comparatively heavy base precludes the likelihood of damage through inadvertence to which a smaller instrument would

be prone. Tully was a jeweller and knew jewellers. The other prominent feature of this instrument is the full hemisphere of dense glass which is mounted in a metal collar and allows

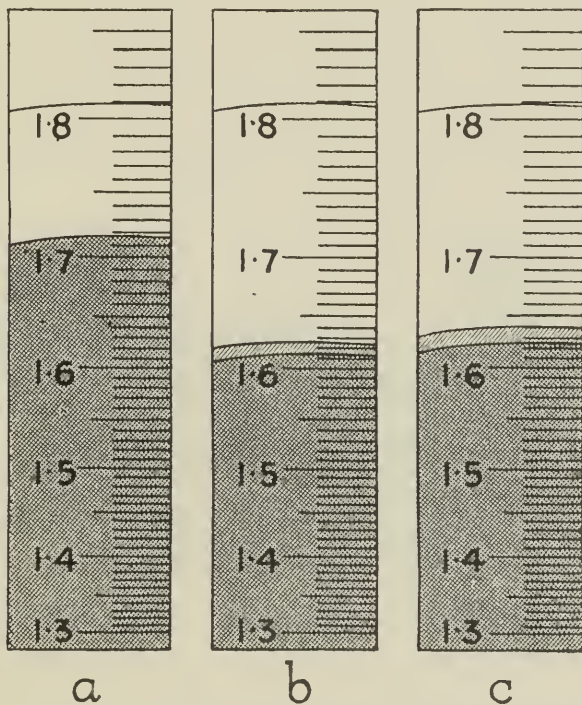


FIG. 32.—Scale of the Tully refractometer. a, reading shown by a singly refractive stone (reading is that of a natural spinel). b, reading shown by a doubly refractive stone (reading that of topaz). c as b, but showing greater separation of the shadow edges, *e.g.*, tourmaline (readings as seen when monochromatic light is used)

the glass to be rotated by the finger. This avoids the liability of damage to the soft dense glass which is likely when the stone is turned on the dense glass by hand. The scale is clear and brilliant and reads up to 1.86 (special models are

made which read up to 1.90). Unlike other refractometers the scale of the Tully is erect (fig. 32), that is, the scale reads from the bottom to the top. A hinged reflector directs the light on to the hemisphere and a convenient cover protects the specimen from top light during an examination.

The RAYNER REFRACTOMETER was brought out in 1936. It has a certain similarity of design to the Smith and Swift instruments, but with an ingenious system of truncated

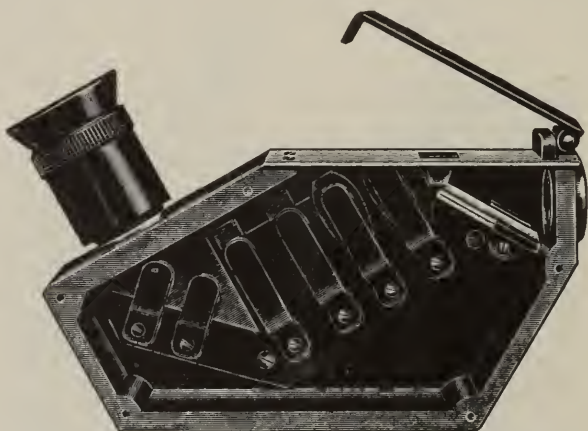


FIG. 33.—The Rayner refractometer, side removed to show construction

lenses and prisms the instrument is made so flat that it takes up little more room than would a stone wallet. There is no hemisphere, the dense glass being made in the form of a small prism, this makes a very small table which, however, is in some ways an advantage. Fig. 33 shows the Rayner refractometer. The scale of the Rayner, unlike the Tully, is inverted. It reads to 1.86. There is a top light cover and an exceptionally quick acting focussing device to the eyepiece. No light reflector is necessary with this instrument so none is provided. Like the Tully, the Rayner is a product of Rayners.

The ANDERSON-PAYNE SPINEL Model of the RAYNER REFRACTOMETER has the same optical arrangement as the ordinary Rayner instrument, but in place of a dense glass prism there is a prism of synthetic white spinel. The function of this instrument, which will read up to 1.70 only, is to make easy reading of those gemstones, and they are by far the majority, which have indices below 1.70. The dispersions of the white spinel and most gemstones are very similar, so that in ordinary white light the shadow edges, even in weakly birefringent stones, can be quite clearly seen.

The ANDERSON-PAYNE DIAMOND Model of the RAYNER REFRACTOMETER has a dense "glass" made of a diamond. It has a scale which extends from 1.55 to 2.05, so long that the eyepiece is made to run on a track so that any desired part of the scale can be viewed. With this instrument, in order to utilize the high range, it is necessary to use either of the highly refractive liquids, such as West's solution or selenium bromide. It is recommended that sodium light be used. A similar instrument has been made which uses for the prism the mineral zinc blende.

The instruments which have just been discussed are all of British manufacture. It may be interesting to consider what types of refractometers are used in Germany, France and the United States of America. Germany is generally considered to be pre-eminent in the production of optical instruments, and indeed in some of the laboratory refractometers of the Abbe-Pulfrich type (a type where the critical angle is accurately measured by means of a telescope and divided circles and verniers) are exceptionally fine, but in commercial instruments the Germans do not appear to have matched their British counterparts. They have a number of good instruments of fine optical quality, but, as far as is known, no German instrument reads higher than 1.75, which is of no use for the important gem corundum. France does not appear to have a really French refractometer, although the pioneer Bertrand was a Frenchman, and German instruments seem to be used in France. To date (1945) the Tully

and Rayner have proved most popular in the United States, though it is expected that one or more gemological refractometers will soon be manufactured in this country.

It may be an advantage to give a few hints on the care of refractometers. In the instruments which have a hemisphere of dense glass, this hemisphere is very soft, far softer than are the gemstones which are placed upon it, hence it is essential to ensure that the polished surface is not scratched by careless placing of the gemstone on the table. **Tweezers** should be used to place and centre the stones whenever possible. Liquid should be carefully removed after the refractometer has been in use (many of the contact liquids have a detrimental effect if left for long on the glass). Blotting paper is best to clean and absorb the liquid from the glass. Before putting the instrument away after use the dense glass should be wiped and then smeared with a film of vaseline. Occasionally the glass table should be gently polished with a clean leather and jewellers' rouge.

For good results—

Don't spoil the polish of the glass hemisphere.

Don't try and get a reading with a dirty stone.

Don't put your instrument away in a dirty condition.

The use of the refractometer is the jeweller's most important method of refractive index determination, but, as has been mentioned before, is not the only method whereby this constant can be measured, some of these other methods do have, at times, a practical use in the discrimination of gemstones.

The **METHOD OF MINIMUM DEVIATION** is one of great accuracy. It requires the use of an expensive instrument, the spectrometer, and is a method for the use in the laboratory only, hence, will not be discussed at length. The **DIRECT MEASUREMENT** or, as it is termed, **DUC de CHAULNES' METHOD** is useful for specimens which have two parallel sides, such as a small octahedron of diamond, or even the top or table facet and the culet (the small facet at the base of a cut stone



and parallel to the table) in a brilliant cut stone. If one of these parallel surfaces is placed on a glass slide on the stage of a measuring or petrological microscope fitted with a calibrated fine adjustment and the microscope is focussed on to the uppermost of the two parallel faces, a reading is made. A second reading is made when the microscope is focussed on to the lower face as viewed through the specimen. The difference between these two readings gives the apparent depth of the specimen. Then, by pushing the glass slide along and focussing the microscope on to its surface and taking a reading, we are able, by ascertaining the difference between this reading and the reading of the top face, to calculate the real depth of the stone. The simple calculation:—

$$\frac{\text{real depth}}{\text{apparent depth}}$$

gives the refractive index.

BECKE'S METHOD is useful when small fragments may be chipped from the specimen, such as may be possible from the base of a carved figure.

The chip is first of all placed on a microscope slide with a drop of liquid of known R.I. (*any of the liquids named as contact liquids for refractometer use are applicable. They may be reduced to any R.I. by dilution with one lower in the scale, e.g., methylene iodide may be diluted with monobromonaphthalene*). The slide is placed on the stage of a microscope and the chip accurately focussed. On raising the microscope tube from the position of exact focus, a white line is seen at the margin of the specimen and liquid, which travels into the medium of higher refraction. Hence, whether the index of the specimen is higher or lower than the liquid of known index, or between two such liquids, may be easily determined.

The IMMERSION METHOD is useful where small stones are not easily "get-atable," for example: a cluster ring contains some white stones which may be diamonds or synthetic white sapphires or spinels. The method is based on the fact that when a specimen is immersed in a liquid having a similar

refractive index to itself the relief is low, *i.e.*, the edges tend to disappear. Readers will recall that it is this phenomenon which is used as a basis by H. G. Wells in his fantasy, *The Invisible Man*. To put the method into practice, the specimen is immersed in one liquid after another until one is found in which it most completely disappears. It is then known that the specimen must have a refractive index approximating to that of the liquid. Should the position be, as quoted in the example of the ring above—where it is required to know whether the stones are diamonds or one of the synthetic white gems—it is not necessary to obtain an accurate approximation between the liquid and stones, for, if the ring is immersed in a small cell, preferably of white china or else standing on a white surface, containing monobromonaphthalene or methylene iodide, the stones, if diamonds, would stand out in high relief and, if either of the synthetics, low relief.

Below is appended a short list of the refractive indices of the principal gemstones. Doubly refractive stones are shown with their maximum and minimum indices of refraction.

Diamond	...	...	...	2.42	
Zircon	...	...	...	1.92	1.98
Sphene	...	...	...	1.9	2.0
Garnet (demantoid)	...	...		1.89	
Garnet (almandine)	...	...		1.79	
Corundum (ruby and sapphire)			1.76		1.77
Garnet (pyrope)	...	...		1.75	
Chrysoberyl	...	...	1.75		1.76
Garnet (hessonite)	...	...		1.75	
Spinel	...	...	...	1.72	
Peridot (olivine)	...	...	1.66		1.70
Spodumene (kunzite)	...	...	1.66		1.68
Tourmaline	...	...	1.62		1.64
Topaz	...	...	1.62		1.63
Beryl (emerald, etc.)	...	...	1.57		1.58
Quartz (rock crystal, etc.)	...	...	1.54		1.55
Opal	...	...	...	1.45	



### Recapitulation

A refractometer is an instrument for the direct reading of refractive index. It operates by observing the shadow edge caused by the critical angle of total reflection on a suitably calibrated scale. Limits of use are caused by (a) "dense glass" of instrument which must be higher than stone to be tested, (b) a film of liquid which must have an index of refraction greater than the stone under test. Monochromatic light (usually yellow sodium light) necessary for observations of double refraction (birefringence).

Refractive index determination by Becke's method is useful for small fragments; immersion method for certain awkward cases (only approximate), while the direct measurement method has fair accuracy but limited scope. The method of minimum deviation is extremely accurate but requiring expensive apparatus and is time-consuming.

### Test Questions

22. Name three gemstones which give *negative* readings on a Herbert Smith refractometer.
23. What auxiliary apparatus is needed in conjunction with a refractometer to measure accurately the amount of double refraction?
24. What is meant by the term *birefringence*?
25. Who enunciated the laws of refraction?
26. What is an optic axis and how many such axes are there in stones belonging to the rhombic system?
27. What make of refractometer has a rotatable "dense glass," and which instrument was the first to have a scale calibrated in indices of refraction?
28. How would you find the refractive index of a stone expected to be a sphen and which is found to have two parallel faces?

## CHAPTER VII

### COLOUR IN GEM DISTINCTION

IN most transparent gemstones colour is an accidental quality and, in general, gemstones are colourless when in the pure state; for example, pure corundum (oxide of aluminium) is colourless (white sapphire), but when containing a very small percentage of the oxide of the metal chromium it is red (ruby), and when the impurity is a combination of the oxides of iron and titanium the colour is blue (sapphire). When the colour is caused by a trace of an accidental impurity the mineral is termed *allochromatic*. When the pigmenting material is an essential constituent of the mineral it is termed *idiobromatic*. The colour nuances exhibited by the various gemstones do provide a degree of assistance in their recognition to the gemological expert, but colour can never be an absolute guide as to the species of a stone and reliance can only be placed on accurate determination by the use of instruments.

It will be recalled that in the chapter on "Light" it was stated that when white (mixed) light passes through a coloured medium certain wave-lengths (colours) may be absorbed and the residual colours reaching the eye are blended together and produce the colour of the stone, *i.e.*, selective absorption. Also it has been learnt that gems belonging to certain crystal systems split a ray of light into two rays. What happens then with such a stone—do both these rays undergo similar selective absorption, or do they differ one from another?

With doubly refractive stones there is often a difference in the selective absorption in the two rays, termed *differential selective absorption*, thus causing a difference in their colour. This effect is termed *dichroism* and is a valuable testing factor

in gem testing. The effect of dichroism is rarely seen by the eye alone owing to the short distance the two rays travel through the stone; hence, in order to observe these *twin*

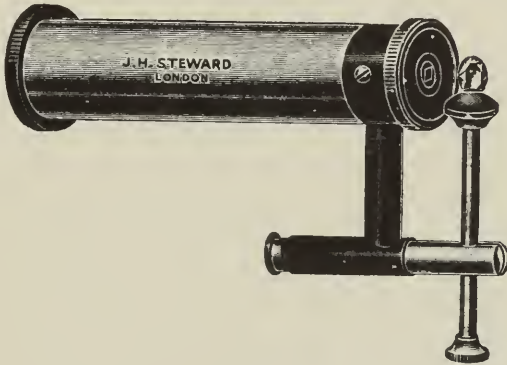


FIG. 34.--The Steward dichroscope with stone holder

*colours*, as they are called, an instrument is necessary. This instrument is termed a *dichroscope* (fig. 34).

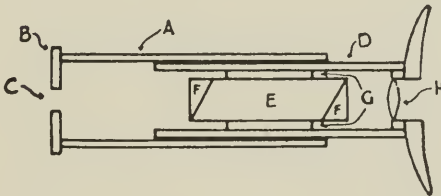


FIG. 35.—Sectional drawing of a dichroscope showing the optical system

The dichroscope (fig. 35) consists of a short metal tube (A) closed at one end by a metal endplate (B), which has at its centre a square aperture (C). Into this tube slides another metal tube (D) which contains a rhomb of calcite (E), to the

ends of which are cemented glass prisms (FF). The calcite rhomb is held securely in the tube by cork packing (GG) and at the end of the tube is fitted a low power lens (H). The instrument may be focussed by sliding the inner tube in or out, and some instruments have a special holder upon which the stone is fixed by wax to enable it to be more easily rotated.

On looking through the dichroscope at a light two images of the square aperture (C) are seen side by side, due to the strong double refraction of the calcite. To test a stone we place it close to the aperture, either on the stone holder or held by tweezers, and view it through the instrument held up to the light. If the two squares show identically the same colour the stone is *monochroic* and most probably singly refractive, but, if the two squares show a different colour, or even two different shades of the same colour, the stone is *dichroic* and MUST be doubly refractive.

Dichroism is due to double refraction, and therefore can never be seen in a singly refractive stone. It cannot, for obvious reasons, be observed with colourless or white stones. even if they are doubly refracting, the dichroscope is only useful for coloured gems. Dichroism may be so feeble that it cannot be observed even by the dichroscope, and it is essential to remember that if a doubly refracting stone is examined by the instrument along the direction of an optic axis, no dichroism is seen even in a strongly dichroic stone. This is because the optic axis is a direction of single refraction in a doubly refractive stone; this must be carefully guarded against when testing. The stone must be rotated and viewed through several different directions. The slightest difference in the colour of the two squares (or shade of the same colour) marks the stone as doubly refracting; it is not the exact colours that form the test but the fact that this difference in colour does or does not exist. The presence of "twin colours" is a sure sign that the stone is doubly refracting, but absence of dichroism does not necessarily mean that the stone is singly refracting.

The dichroscope will readily distinguish: EMERALD from paste, soudé emerald (a composite stone) and "jewelers' olivine" (green garnet); RUBY from paste, red spinel, "cape ruby" (garnet); SAPPHIRE from paste, or blue spinel.

The dichroscope will not differentiate between the natural stones and their *synthetic* counterparts, for these latter gems have the same characters as the natural stones.<sup>1</sup>

It has been explained that when a ray of white light is passed through a prism of glass, or for that matter, any other transparent medium, the ray will be *dispersed* into the familiar rainbow colours—red, through orange, yellow, green, blue, to violet. When Sir Isaac Newton in the year 1666 observed this effect, and thus showed that white light is composite, he paved the way for the *spectroscope*, one of the most powerful weapons known to present-day physical science.

Newton's first experiment, consisted of passing a beam of sunlight, from a circular aperture in a shutter, through a glass prism and receiving the resulting colour band on a suitably placed screen. The aperture was of necessity rather wide and the colours of the resulting spectrum tended to overlap one another. That is, the spectrum was not *pure*. In 1802 Wollaston improved on the experiment by employing a ray of light which has passed through a narrow slit, which functions as a point of light in one dimension. Later, an optician of Munich named Fraunhofer obtained a better spectrum on the screen by placing a convex lens between the slit and the prism, and for viewing the spectrum directly a telescope was fitted between the prism and the eye. Fraunhofer also experimented with a *grating* in place of the prism, thus following up the enunciation by Thomas Young in 1801, of the principle of interference.

The fundamental colour of a gemstone, as has been mentioned previously, depends upon which wave-lengths (colours) are absorbed from the incident white light. The residual colours, *i.e.*, those not absorbed, pass through the

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<sup>1</sup> The Shipley hand polariscope can also be used as a dichroscope. See Plate A.

stone and combine to produce the colour of the stone. Hence if light which has passed through a stone is examined by a spectroscope, it will be seen that those parts of the spectrum totally absorbed appear as dark spaces, and those partially absorbed as areas of low intensity. Careful examination will show that many stones have sharp dark (sometimes bright) lines crossing the bright parts of the spectrum which often afford valuable additional evidence as to the nature of a stone.

These *absorption spectra*, as they are termed, were first considered in relation to gemstones through the publication, by A. H. Church in 1866, of notes on the narrow dark bands seen in the spectrum produced when white light has passed through a zircon. In recent years E. T. Wherry in America and B. W. Anderson with C. J. Payne in this country have carried out research and published data of the absorption bands found in many of the gem materials. These absorption bands are in general due to some chemical compound or compounds which are an impurity in the stone and which may, or may not, be the cause of the stone's colour.

Those stones which show pronounced absorption bands and thus assist in their identification are listed below:—

ZIRCON usually shows many sharp dark lines crossing an otherwise-clear spectrum. The strongest and most prominent are at 6600A, 6535A, 5890A. (Table appended below this list shows where these measurements are in the colour band.) The "fired" white and blue zircons may show only the line at 6535A and then only faintly. These absorption bands are due to a trace of compounds of uranium.

RUBY shows absorption bands due to an oxide of the metal chromium, to which compound is also due the colour of the stone. This spectrum then shows a broad absorption in the yellow and green and in the indigo and violet. This leaves a "window" in the blue in which may be seen three sharp lines at 4750A and 4680A. The line at 4750A is seen with an instrument of large dispersion to be two lines very close together; this is termed a *doublet*. Examination of the red and

orange end of the spectrum shows several dark lines, such as one at  $6590\text{\AA}$  and one at  $6930\text{\AA}$ , which, instead of being dark, is generally seen as bright red (due to a fluorescence effect) and under high dispersion this bright red line is seen to be a close doublet.

EMERALD, which is also coloured by chromium, shows in general a similar type of spectrum to that of ruby except that the broad absorption is not so pronounced. There are no strong lines in the blue. The lines in the red are all sharp and are dark. The most prominent bands are at  $6830\text{\AA}$ ,  $6805\text{\AA}$ ,  $6620\text{\AA}$ ,  $6460\text{\AA}$  and  $6295\text{\AA}$ .

ALEXANDRITE shows bands due to chromium and somewhat similar to emerald. The important lines are at  $6795\text{\AA}$ ,  $6510\text{\AA}$  and  $6450\text{\AA}$ .

RED SPINEL is also coloured by chromium and shows a typical chromium spectrum without the lines in the blue "window." It shows a dark band at  $6560\text{\AA}$  and a "band" made up of four or five lines close together which are often bright red (fluorescent lines).

DEMANTOID GARNET is most certainly coloured by chromium, but owing to the general absorption in the red it is difficult to find lines so characteristic of that metal. At  $4420\text{\AA}$  there is an absorption band due to iron which, owing to the general absorption of the violet, may appear as a sharp cut-off when no violet is seen beyond the band.

PERIDOT shows a spectrum due to iron compounds which are actual ingredients of the stone and not an impurity. Three bands are seen which are rather broad and are centred at  $4970\text{\AA}$ ,  $4730\text{\AA}$  and  $4530\text{\AA}$ .

BLUE SAPPHIRE shows a band, generally rather sharp, at  $4500\text{\AA}$ . This band may not always be seen (*see note under synthetic blue sapphire*).

GREEN SAPPHIRE shows the band at  $4500\text{\AA}$  as seen in the blue sapphire, only much stronger and with other bands at  $4710$  and  $4600$ . Both in blue and green sapphire the band is due to iron compounds.

ORANGE-YELLOW SAPPHIRE shows the iron band at  $4500\text{\AA}$



as for the blue and green sapphires. This band is seen particularly strongly in the blue, green and orange sapphires from Australia.

GREEN TOURMALINE shows a band at  $4980\text{\AA}$  which is due to iron.

YELLOW CHRYSOBERYL shows an iron band at  $4440\text{\AA}$ .

ALMANDINE GARNET shows several broad bands, the most easily seen being the three centred at (a)  $5740\text{\AA}$ , (b)  $5260\text{\AA}$  and (c)  $5040\text{\AA}$ . In dark specimens (b) and (c) may look like one broad band.

PYROPE GARNET in general contains some percentage of almandine in its constitution, and hence shows the almandine bands although somewhat less strongly. If the stone approximates to nearly pure pyrope, that is to R.I. = 1.74 and S.G. = 3.68, the spectrum is reminiscent of that for red spinel. The lines in red are not so easily discerned and there are *never* any fluorescent lines.

#### SYNTHETIC GEMS

Synthetic ruby shows a similar spectrum to that of the natural ruby. Synthetic blue, green and orange sapphires *never* show the iron band at  $4500\text{\AA}$ . (*If a suspected stone is found to show this band in the blue-violet the stone must be natural. Absence of the band does not necessarily prove that the stone is synthetic, for some natural blue sapphires have been found which do not show the band, or show it too weakly for it to be easily seen.*) Blue synthetic spinels show a spectrum due to cobalt; these stones usually imitate the blue zircon and the blue aquamarine. The spectrum consists of three broad bands centred at  $6350\text{\AA}$ ,  $5800\text{\AA}$  and  $5400\text{\AA}$ . The yellow synthetic spinel shows a spectrum having two bands in the blue-violet at  $4450\text{\AA}$  and  $4220\text{\AA}$ . This spectrum is probably due to manganese and may be found in combination with the cobalt spectrum mentioned previously. The "Alexandrite" types of synthetic corundum and spinel do not show the bands in the red as are found in the natural Alexandrite chrysoberyl.

TABLE OF APPROXIMATE WAVE-LENGTHS

7500Å to 6500Å	...	...	...	RED.
6500Å to 6000Å	...	...	...	ORANGE.
6000Å to 5500Å	...	...	...	YELLOW.
5500Å to 5000Å	...	...	...	GREEN.
5000Å to 4500Å	...	...	...	BLUE.
4500Å to 4000Å	...	...	...	VIOLET.

As to a choice of instrument best suited for the examination of the absorption spectra of gemstones the most useful seems to be the direct-vision hand instruments which have a fairly high dispersion. Whether the instrument is one of the

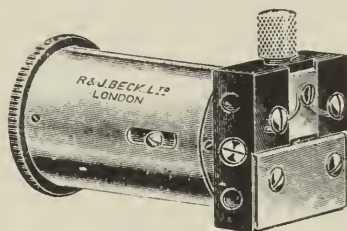


FIG. 36.—The Beck direct vision spectroscope No. 2447

prism type, or the type which functions by the principle of interference by the use of a diffraction grating, is of little consequence. It should be noted, however, that the grating instrument produces a spectrum in which the dispersion is uniform throughout the scale, whereas the spectrum produced by the prism instrument is found to be bunched-up at the red end and has a much wider dispersion at the violet end. On the other hand, a prism instrument affords a brighter spectrum, somewhat easier to interpret. A detail which should be mentioned is that either type of instrument should preferably be provided with an adjustable slit. An instrument found most suitable in general practice is the direct-vision diffraction-grating instrument with adjustable slit (fig. 36). This instrument has a dispersion of  $20^\circ$ .

There are two usual methods of observation with the

spectroscope—by transmitted light and by scattered light. The best technique for transmitted light is to use the spectroscope in conjunction with a microscope. The specimen to be tested is placed, table facet down, on a microscope slide placed on the stage of a microscope and illuminated by a strong source of light *via* the mirror and the substage condenser. Using a low power objective (1 in. or  $1\frac{1}{2}$  in.), the eyepiece is removed and the microscope focussed until the whole field of view in the body tube is filled with bright light which has passed through the specimen. This light is viewed with the spectroscope, which is held in place of the microscope eyepiece. The Beck no. 2447 illustrated (fig. 36) is large enough to rest on the top of the tube. To examine by scattered light the stone is fixed to a stand by wax and illuminated by a strong light; the microscope stand condenser is useful to converge the light on to the specimen, and the spectroscope held in the hand and directed on to the stone, the spectroscope thus analyzing the light that is reflected and scattered from the stone. This method appears to be the better practice when it is required to observe the bright fluorescence lines and the first explained method for general work.

It has long been known that when an emerald is viewed through certain colour filters generally known in the United States as emerald filters, which transmit a band of red and a band of green light the stone appears red. This is due to the fact that emerald passes a considerable amount of red light. These filters have been made in various forms. The type in most popular use in the United States is that which consists of two gelatine filters between glass plates. The filter, as before mentioned, shows emerald as red and its glass and doublet (composite stones, as *soudé* emerald) counterfeits as green, thus giving a clear distinction between the two. It must be mentioned that all other green gemstones also show green through the filter, with the exception of green zircons, demantoid garnets and the stained chalcedony coloured by chromium compounds. The filter also differentiates between the synthetic blue spinels from the blue zircon and aqua-

marine which they simulate. The spinels show orange or red through the filter, while the natural stones show greenish. Rubies and red spinels appear to glow with their own light (fluorescence effect) when viewed through the filter, while garnets appear dull and lifeless.

Certain gemstones have been found to emit light under conditions of excitation from exposure to the rays of ultra-violet light, cathode rays, X-rays and emanations from radioactive minerals. When the glow of light persists only so long as the exciting radiation is impinging upon the specimen the effect is termed *fluorescence*. If the glow persists after the exciting radiations have been cut off the effect is termed *phosphorescence*. There is no essential difference between the two effects. Diamonds, rubies, red spinels, fluorspar (*from which stone the name "fluorescence" was derived*), many synthetic spinels and pearls, etc., show the phenomenon particularly well. Beautiful as the effects appear to the eye, fluorescence and phosphorescence have been found to have little application in gemology. Methods employing this phenomenon in the detection of synthetic gems and cultured pearls have met with scant success.

### **Recapitulation**

Colour is due to some small percentage of an impurity (allochromatic) or to a pigment which is an essential constituent of the mineral (idiochromatic).

Differential selective absorption of light is found only in doubly refractive materials. It is a difference in the colour of the rays of doubly refractive material. Generally termed dichroism or trichroism in the case of the three rays of biaxial stones. Pleochroism is the collective term for the phenomenon.

A dichroscope is an instrument for detecting differential selective absorption in coloured stones.

Absorption spectra, examined by a spectroscope, show the absorbed areas of the Newtonian spectrum. These spectra have a use in gem distinction.

### **Test Questions**

29. State which of the following stones are likely to show dichroism: Tourmaline, Spinel, Kunzite, Opal, Sphene.

30. Is there any difference with regard to the cause, as apart from the effect, between chatoyancy and asterism?

31. A red stone weighs one quarter less in water than in air. What is its specific gravity and hence its identity?

32. Suggest two reasons why a stone gives no reading on a refractometer.

33. Which of the following groups of figures are wrong? and correct them in relation to the stone named:

R.I.—3.52, S.G.—2.42 = Diamond.

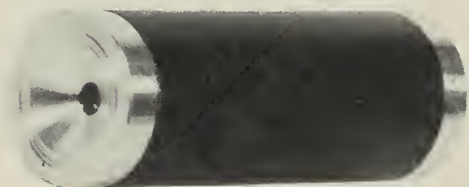
R.I.—1.55, S.G.—2.65 = Quartz.

R.I.—1.92, S.G.—3.33 = Spinel.

R.I.—1.45, S.G.—3.1 = Opal.



Left: Hardness pencils; 5, 6 1/2, 7, 7 1/2, 8, 9, 10. Approximately one-third actual size. (*Gemological Institute of America.*)



Above: Dichroscope, actual size. (*Gemological Institute of America.*)



Above: Shipley polariscope on sub-stage lamp. Right: Shipley polariscope showing revolving stone holder and interior of chamber. One-half actual size. (*Gemological Institute of America.*)

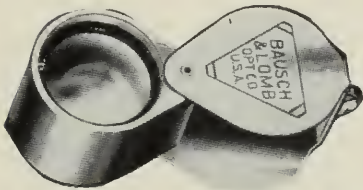








Rayner refractometer (Rayner and Keeler, Ltd.) in position for use with monochromatic lamp and transformer. Designed for use with other refractometers when lamp is in upright position. (*Gemological Institute of America.*)



Loupe or triplet (10x) corrected for spherical and chromatic aberration. (*Bausch & Lomb Optical Co.*)



ShIPLEY calibrated universal immersion stage. (*Gemological Institute of America.*)



Bausch & Lomb microscope equipped with Bertrand lens and quartz wedge. ShIPLEY calibrated universal immersion stage shown in position for use.





Diamolite with accessories (*Gemological Institute of America*), including 4x head magnifier (*Edroy Products Co.*), for use in grading diamonds for slight differences in body color.



Left: Diamondscope equipped with  $10\frac{1}{2}x$ ,  $22\frac{1}{2}x$  and  $105x$  magnification quickly interchangeable;  $105x$  used only for gemstone identification. (*Gemological Institute of America.*)

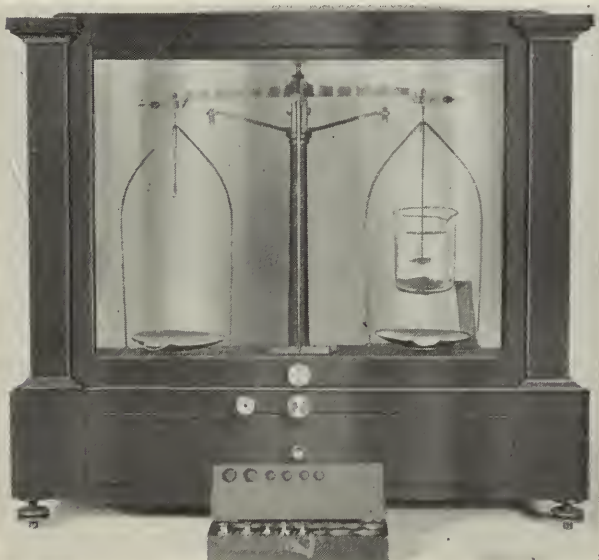
Duralumin eye loupe containing 10x triplet corrected for chromatic and spherical aberration. (*Gemological Institute of America.*)







Special laboratory lamp with alternate filters for excitation of fluorescence, especially in diamonds, and for production of monochromatic yellow light for use with refractometer. (*Gemological Institute of America.*)



Jeweler's diamond balance (*H. Kolbusch & Co.*) with accessories in place for determination of specific gravity of gemstones.



## CHAPTER VIII

### THE MICROSCOPE

THE last instrument to be discussed is the microscope, which, in the simpler types, is simply a convenient carrier for a compound system of lenses, means for the adjustment of their focus and for control of the illumination of the specimen under examination. The primary function of the microscope is to give an enlarged image of an object set at its focus. The instrument performs in a much better manner, and with a



FIG. 37.—Hand magnifier

much greater magnifying power, the duty of a simple hand magnifier (or loupe) (fig. 37) which is indeed itself a simple type of microscope.

The instrument (fig. 38) consists of a *foot*, to which is attached by trunnions, so that the instrument may be used vertically or in an inclined position, the *limb* complete with *body tube* and its rackwork for focussing. The *eyepiece* and *objective* are mounted at either end of the body tube, which is of such length that these two lens systems correctly amplify one another. The focussing adjustments are two in number, a *coarse adjustment* by spiral rack and pinion, and a *fine adjustment* controlled by a finely-threaded screw system.

Below the body tube, and fixed to the limb, is the *stage*, which is a metal plate (or platform) with its plane at right



angles to the length of the body tube. This platform, upon which is placed the object to be examined, has an aperture at its centre (that is in the optical axis of the instrument) and is usually provided with spring clips to hold the plain glass specimen slips. Below the stage is a continuation of the limb which carries an arm to which is fixed, in a gimbal device, a

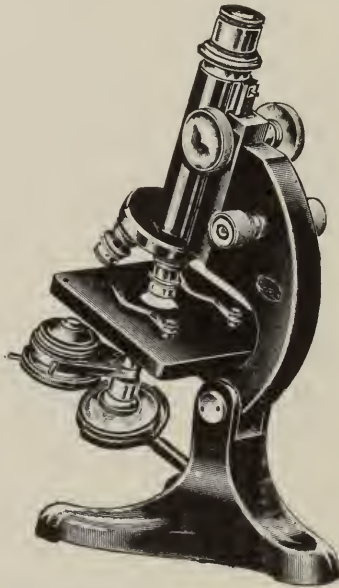


FIG. 38.—The “No. 29, London” microscope by R. and J. Beck Ltd., London

mirror for directing a beam of light through the aperture of the stage, through the specimen under examination and up through the objective, body tube and eyepiece. This mirror is a double one, one side being plane and the other slightly concave; the former is to be used in daylight and the latter with artificial light so as to obtain as nearly as possible parallelization of the beam of light passing up and into the instrument.

The magnifying power of a microscope is altered by the use of objectives of different focal length and can be altered also with a change of eyepiece. For gem-testing work an objective of a  $\frac{1}{4}$  in. focal length is the most powerful which can be employed; it will be found, however, that powers of  $\frac{2}{3}$  in. and 1 in. are the most suitable for all general work, for the focal length is wide enough comfortably to clear the stone with the addition of a bright and wide field of view. Should the stone under test be set, say in a ring, and it is necessary to observe the stone when it is immersed in a liquid (see later), the shank of the ring is found to stick upward and hence prevent the objective being lowered sufficiently to "get into the stone," a  $1\frac{1}{2}$ -in. objective will be found to give sufficient clearance in such a case. A useful accessory for a microscope is a substage condenser, consisting of a "bee-hive" lens system and completed with an *iris* diaphragm, the whole being arranged to allow for movement up and down and also for the whole condenser to be swung clear of the optical axis of the microscope.

The use for such a microscope as has just been described is primarily for the examination of the surface and internal structure of gems, as in the case of suspected synthetic stones (*the difference between the structure of natural and synthetic stones will be discussed in a later chapter*). This simple type of microscope is also suitable to carry out the Becke test described in the chapter "Refractive Index Measurement." To use a microscope the instrument should be placed before a window or a table lamp on a firm table with the tube in a vertical position. The mirror should be adjusted so that the maximum amount of light enters the lower lens system, *i.e.*, the objective which should be the one with the power it is required to use. On looking down the eyepiece the field of view should be seen to be quite bright. If a gemstone is now placed on a glass slip resting (or clipped) on the stage it will be seen that even when the microscope is carefully focussed with the coarse adjustment (the fine adjustment is rarely necessary with any objective over  $\frac{1}{2}$  in. in focal length) the inside of

the stone can hardly be seen. This is due to reflections from the surface of the stone; hence it is necessary to use another technique to enable the internal structure to be seen. To a certain extent these surface reflections may be overcome by the use of the substage condenser; the best method, however, is to view the stone when it is immersed in a vessel of glass filled with highly refractive oil.<sup>1</sup> The oil or liquid should



FIG. 39.—Petrological microscope

have nearly the same index of refraction as the stone being examined, and the two most commonly used are methylene iodide and monobromonaphthalene. To avoid damage to the soft glass of the objective lens care should be taken not to rack the tube down on to the stone. If the microscope is first lowered nearly on to the cell of liquid and stone while looking sideways to ensure that the objective does not come in contact with the surface of the liquid, the observation can then be made by raising the tube and thus bringing the bottom edge of the stone into focus first. Further slow racking up will enable the observer to view the inside of the stone from bottom to top, that is, the stone will have been "worked through" without any danger of the

microscope being racked down on to the stone with the consequent damage to the objective or to the cell.

All of the above disadvantages to obtaining a clear view of the interior of the stone are overcome in the patented *Diamondscope* (see Plate A), manufactured in the United States. This instrument combines a specially designed dark-

<sup>1</sup> A universal motion stage designed especially for this purpose is available in the United States.

field illuminator with a binocular microscope. The illuminator is specially designed to bring out inclusions in faceted gems; and the binocular microscope, with its stereoscopic vision and long working distance objectives, permits ready observation of inclusions, even in stones mounted in finger rings. Other instruments employing the same basic principle, and made under the same patent, are the G.I.A. Diamond Imperfection Detector (Plate I) and the Gemolite, also manufactured in the United States.

The microscopes discussed so far are used primarily to study the inclusions in gems. In addition to such observation, some microscopes are fitted with an arrangement to produce plane polarized light in order that specimens may be viewed with such light. The best types, and incidentally very expensive, of these microscopes are the *petrological microscopes* (fig. 39) used by mineralogists and geologists in the study of rocks. They are fitted with a stage which is capable of rotation and graduated in degrees. They are supplied with an *analyzer* and *polarizer*, which are special prisms of calcite termed Nicol's prism after their inventor, and the fine adjustment is graduated to read 1/100 millimetres—that is the amount the tube has been raised or lowered by altering the fine adjustment can be determined from the difference in the readings of the first position and the second. This is particularly useful when it is necessary to determine the refractive index by the direct measurement method described in the instalment on refractive index measurement. The best petrological microscopes have other accessories, which have little use in general testing and will be ignored for the purpose of these notes.

One point that cannot be ignored is the use of polarized light in the testing of gemstones. As before mentioned, ordinary light vibrates in all directions perpendicular to the path of the ray, while polarized light has only one direction of vibration perpendicular to the path of the ray. In doubly refracting crystals (remember all crystal systems other than the cubic system are doubly refracting) the two rays are plane polarized in directions at right angles to one another. Now

if plane polarized light can be produced which is vibrating in the direction, say, east/west (in the plane of the paper) and above it, plane polarized light can be produced vibrating north/south, the ray from the first polarizer will be unable to get through the second polarizer, or as it is termed, the *analyzer*. This position of two polarizing pieces is termed the *crossed position*. If between these two polarizers is placed a doubly refracting stone which has the two rays of its double refraction vibrating in the east/west and north/south positions, it will be obvious that the stone will have imposed no new vibration-directions on the rays, and thus the "crossed" effect of polarizer and analyzer is still maintained and no light is transmitted. On rotating the stone, however, the vibration-directions are no longer dead against either nicol and a certain amount of light passes. The maximum light is seen at  $45^\circ$  to the "extinction" position. If an apparatus is arranged whereby a polarizer and an analyzer are respectively below and above a rotating stage (to carry the stone), assuming the polarizers to be in the crossed position and a doubly refracting stone between them, a rotation of the stage with the stone will give a field which is four times light and four times dark. This is a proof of double refraction. Singly refractive materials such as glass and cubic minerals give a dark field during the complete rotation.

There are several methods whereby the observation of double refraction by the use of polarized light may be carried out. However, with the exception of a short note at the end, these notes will be confined to the use of Nicol's prisms in conjunction with a microscope. The next consideration is, "What is a Nicol's prism and how does it work?" (these prisms are often called "nicols" for short). The prism consists of two pieces of calcite (Iceland Spar) cemented together by Canada Balsam (R.I. = 1.54) in such a manner that the ordinary ray, having a higher index of refraction than the balsam, is totally reflected at the balsam surface and is absorbed by the casing of the prism. On the other hand, the extraordinary ray, which has a lower refractive index than the balsam, emerges as a completely polarized ray of light at

the other end of the prism (see fig. 40). One of these prisms is mounted in a holder below the stage. This fitting allows this lower nicol or the *polarizer*, as it is termed, to be rotated. The second nicol or *analyzer* is placed in the tube of the microscope above the objective.

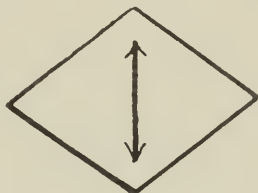
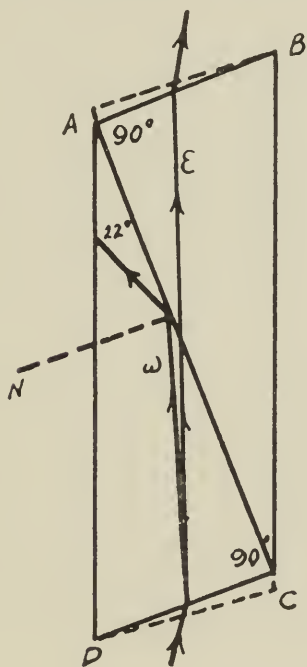


FIG. 40.—Nicol prism showing absorption of the totally reflected ordinary ray and the direct passage through of the extraordinary ray. A, B, C, D = calcite prism. A, C = canada balsam cement layer. N = the normal at the point of incidence of the ordinary ray

Small drawing shows direction of vibration of the emergent ray through the top end of the nicol prism

In order to use the microscope for the detection of double refraction the instrument is set up as for ordinary observation and the nicols are placed in the optical axis of the instrument. In the best instruments the analyzer is constructed so that it can be pushed in or out of the tube; in others the analyzer has to be screwed on to the tube in place of the objective, which is then screwed into the bottom of the nicol. All types allow the lower nicol to be swung out of the optical axis, in a similar manner to the condensing lens. With the



nicols in position they are *crossed* by rotating the lower prism until no light is seen through the microscope eyepiece (the better instruments have a click which sets the lower nicol in the crossed position). The stone to be examined is now placed in a cell of highly refractive liquid, the whole placed on the stage and focussed. The rotating stage is then slowly turned through a complete circle. If the field remains dark the stone must be singly refracting, but if alternately light and dark four times during a complete revolution the stone must be doubly refracting and hence belong to either the hexagonal, tetragonal, rhombic, monoclinic or triclinic crystal system. Some glasses and some stones of the cubic system may be found that will show light through a different position during a complete rotation; this is due to strain and is termed *anomalous double refraction*. Careful observation shows that this patchy brightness never takes place sharply at every quarter revolution.

An instrument specially designed for study of cut gems in polarized light is the American invention called the Shipley hand polariscope (see Plate A). Instead of the conventional Nicol prisms, this instrument employs a polarizing film known as "polaroid." The gem is inserted in a light-tight cylinder which is rotated between crossed polaroids. The effects seen are identical with those observed in a polarizing microscope, except that magnification is not usually required. If a magnified image be desired, this polariscope may be used in conjunction with a loupe, or on the stage of the beforementioned Diamond-scope.

### **Recapitulation**

A microscope is simply an instrument for obtaining an enlarged view of an object.

To obtain a clear view, free from stray reflections, of the inside of a stone, it is necessary to immerse the stone in a liquid having a similar refractive index to it.

A polarizing microscope allows the object to be viewed in polarized light.

A Nicol's prism is used for the production of polarized light. It operates by the use of the strong double refraction of calcite, one ray (the ordinary ray) being internally reflected and absorbed



while the other (the extraordinary ray) is allowed to pass through. Doubly refractive material has each ray plane polarized in directions at right angles to one another.

Isotropic materials show a dark field between crossed nicols during a complete rotation of the stage. Anisotropic material show four times light and four times dark.

### ***Test Questions***

34. What is meant by the habit of a crystal?
35. What peculiarity is seen in the absorption spectrum of the red corundum?
36. Give the difference between phosphorescence and fluorescence.
37. Define "fire."
38. Which gemstone has an absorption spectrum made up of a number of narrow sharp lines and who first described this effect?
39. What colour do the blue synthetic spinels which imitate the blue zircon appear when viewed through the emerald filter?

## CHAPTER IX

### THE MOST IMPORTANT GEM SPECIES

HAVING dealt with the basic principles underlying the testing of gemstones, and gained an insight into the working of the instruments used for this purpose, it now seems clear that the next course must entail some discussion of the gem materials themselves. This chapter will, therefore, consist of a survey of the natural mineral species which have a use in jewellery.

It will be seen that the method adopted in these notes is a tabular treatment giving only the essential data. Historical aspects, romance and superstition are ignored. For a full and more complete information on the species the reader is referred to one of the more up-to-date text-books on the subject, such as *Gemstones*; by G. F. Herbert Smith, *A Key to Precious Stones*, by L. J. Spencer, or *Gems and Gem Materials*, by Kraus and Slawson.

*(The following abbreviations will be used throughout this tabulated list: H. = Hardness; S.G. = Specific gravity; R.I. = Refractive index.)*

#### DIAMOND

Carbon (C); Cubic, common forms: octahedron (8 sides), dodecahedron (12 sides), trisoctahedron (24 sides), hexoctahedron (48 sides), and rarely cubes (6 sides). Faces are often distorted and curved, some crystals are almost spherical. Flattened "spinel twin" crystals are common and these are termed "macles." The varieties are (a) Gem variety; colourless and pale shades of pink, blue, yellow, green and brown. (b) Boart; minutely crystalline grey to black crystals useless as gems but powdered for use in cutting and polishing. Term also used for small off-coloured and flawed crystals used for

the same purpose. (c) Carbon, carbonado or black diamond; crypto-crystalline material composed of diamond, graphite and amorphous carbon generally used for industrial purposes, e.g., rock drill crowns.

*H.* = 10. Slight variation with direction, octahedral face the hardest and cube face the softest. Reported variation in hardness of crystals from different localities may be solely due to the existence of twinning. *Cleavage* = octahedral and strong. *S.G.* = 3.52 and is very constant through the purity of the crystals (the impure boart may be as low as 3.15). The lustre of diamond is adamantine and the refraction single. Sometimes anomalous double refraction may be observed which is due to strain. *R.I.* = 2.42. The dispersion is very strong and is exceeded only by sphene, demantoid garnet, cassiterite and blende. This property is, as readers will remember, responsible for the display of colour known as "fire" so well seen in diamond. Under ultra-violet light many diamonds fluoresce, usually sky blue or violet. Diamonds are transparent to X rays. Some yellowish diamonds after long and intimate contact with radium salts become greenish in color and more or less radioactive. Yellowish or colorless diamonds become green or brown when bombarded in the cyclotron. Phosphorescence rarely occurs.

The occurrence of diamond was known from historical times in India, was discovered in Brazil in 1728, South Africa in 1867, British Guiana in 1887, South-West Africa in 1908, Belgian Congo and Angola in 1910 and the Gold Coast in 1919. Diamonds are also found in Australia and Borneo. With the exception of South Africa the diamonds are all found in gravels and conglomerates derived from basic igneous rocks. The name given to the gravel from which the diamonds are found in Brazil is *cascalho*. In South Africa there are two contrasted modes of occurrence (a) River diggings; diamonds found in the river beds around the Vaal river and in alluvial material some several miles each side of the river. (b) "Dry" diggings or mines; consisting of vertical pipes cutting down through various beds of rock to an unknown

depth. These pipes are filled with a rock called "peridotite," a bluish coloured rock with a high iron content termed the "blue ground." Near the surface the "blue ground" weathers to a yellow colour and is then termed the "yellow ground." The surrounding rocks are described as "reef." Diamonds are found in the blue and yellow ground but never in the reef.

Diamonds were also discovered in America in 1906 on the farm of W. J. Huddleston, in Pike County, near Murfreesboro, Arkansas. Occurrence was in a pipe of peridotite similar to that found in certain South African diamond-bearing pipes. The mine has been worked at various times by different companies. During the several periods of activity the mine has produced a considerable quantity of gem diamonds, but none of large sizes. The largest gem weighed 40.23 carats. The pipe has not been worked for a number of years, primarily because the cost of mining exceeded the return of diamonds of sufficient quality to make mining profitable. Glacial diamonds have been found in many localities in the United States. In 1928 a rough diamond which weighed 34.46 carats—apparently the largest glacial diamond ever found in this country—was found in Virginia.

Variations which may affect the beauty or durability of a fashioned diamond are: Color gradations; structure imperfections; proportions of the diamond which affect its dispersion or fire; and finish, which together with its proportions may affect to a marked degree the comparative brilliancy and fire of a diamond and therefore its comparative beauty and value. Accurate judgment of the degree to which such variations have affected the quality and value of a stone depends upon the experience of the individual in handling diamonds and upon the extent of his scientific training.

Defects in diamond crystallization recognized as flaws or imperfections by all diamond merchants are: *Imperfect crystallization*, which may appear as (1) internal fractures known

as "feathers" or cloudy texture," (2) surface fissures or (3) separations along cleavage planes, which may be located within the body of the diamond and may sometimes extend inward from the surface; *included crystals* of smaller diamonds, which practical jewelers had commonly called "colorless bubbles" or "black carbon spots," depending upon the light conditions under which they were observed, until research by Certified Gemologists in recent years revealed their true identity.

Imperfections of finish in cutting and polishing may appear on the surface of fashioned diamonds. Among them, shallow scratches ~~which~~ may easily be polished out are not considered imperfections of finish by some dealers; nor are naturals, tiny portions of the skin of the rough diamond sometimes intentionally left on the girdle by the cutter. "Nicks" or fractures on the girdle of the stone usually occur in wearing or remounting. "Knots," which are tiny included crystals of other diamonds protruding from the surface of a facet, rarely occur. Many diamond merchants class as flaws *any* defects in crystallization or in finish.

A diamond cut in the standard brilliant style has 58 facets. If the angle which the back facets of a diamond make with the plane of the girdle varies to any appreciable extent from  $40^{\circ}$   $45'$ , an unnecessary amount of light escapes through those facets.

Though authorities differ somewhat as to the most desirable sizes and angles in relation to the plane of the girdle, the practice is fairly well standardized. The diamond cutter's skill and the shape or structure of the rough diamond is not always ideal, thus considerable variation in size and placing of facets occurs. Sometimes additional tiny facets are found upon diamonds. Often the girdle is too wide and reflections from it affect the beauty of the stone. Frequently the culet is too large. The sharp point at the bottom of the stone is replaced by the culet facet as a safeguard against breakage.

By present-day mechanical cutting technique a greater amount of weight can be recovered from most rough diamonds by reducing the depth of the portion which lies above the girdle. A stone so cut has greater breadth but less fire than an ideally proportioned diamond of the same weight, and sells for slightly less.

"Perfect diamond" is a term which has become at once especially familiar to the American public and ambiguous. Some jewelers class as "perfect" any diamond within which there are no imperfections of crystallization; others consider absence of surface blemishes a requisite as well; a few merchants insist that "perfect" diamonds should in addition be free of any yellowish tinge. Still others class as "perfect" only those diamonds which also meet specified standards of proportion and finish.

Because of this confusing practice in the American trade, the American Gem Society (United States and Canada) discourages use of the term "perfect" and recommends the term "flawless" to describe a diamond free of imperfections. The Society's Registered Jewelers are required to observe the recommendation and to examine diamonds for imperfections, under adequate lighting conditions, in the Diamondscope or Imperfection Detector, or with a ten-power loupe corrected for chromatic and spherical aberration.

Until 1938, in no nation was there a standard magnification for examining diamonds for imperfections, and magnifications commonly used varied from 3x to 20x. In that year the Federal Trade Commission established 10x magnification as standard in the United States.

Scientific research has in the past few years developed a new technique for examining diamonds for imperfections based on the importance of adequate lighting. Diamond-grading instruments, designed and manufactured in the United States, and known as Diamondscopes and Diamond Imperfection Detectors (see Plate A) incorporate a patented base.

Illumination from the base eliminates reflections from the ordinarily mirror-like surfaces of a diamond which previously obscured imperfections. Examination is made through an attached microscope under ten-power magnification. Another American instrument is the Gemolite, which employs an illuminated base of the same type. The instruments are gradually replacing the loupe which necessitated the diamond man's searching for imperfections among confusing surface reflections.

The standards established by the Fair Trade Practice Rules of the Federal Trade Commission and by the stricter rulings of the Registered Jewelers of the American Gem Society for examination and grading of diamonds for color consider only the body color of the stone. Of diamonds examined for body color under exacting laboratory conditions, some are colorless, but the majority contain varying tints of yellow. If an occasional diamond possesses a bluish body tint it is usually considered a "fancy" diamond and commands a like price.

Color classifications such as Wesselton, Top Crystal, Crystal, Silver Cape, and others, signifying slight differences in tint, were for many years used by leading retail merchants in America. Unstandardized and now largely discontinued, they serve to illustrate the very slight variations in color affecting diamond values. "Jager" formerly described diamonds colorless in body and bluish when observed in sunlight, and more rarely diamonds with a bluish body tint. The latter are actually pale blue diamonds, and are now correctly sold as blue or bluish diamonds. The familiar term "blue white" is one which varies according to the diamond merchant.

In 1941 a Diamond Colorimeter (see illus., Plate A) was completed and installed by the Gemological Institute of America as the result of nine years' research. In it, diamonds are read against a color scale of twelve divisions between colorless and yellow. Jeweler members of the American Gem Society have adopted it as an international "yardstick" upon



which they have diamonds graded for use as master stones in grading their future purchases.

Diamond grading is an exacting activity requiring experience, skill, accurate lighting, efficient equipment. Reflections from colored walls, the sky, or store fixtures may disguise the true body color of a diamond. Daylight, especially that not first passed through glass to absorb the ultra-violet ray, causes fluorescent diamonds to appear less yellowish or more bluish than does artificial light. During recent years an increased number of fluorescent diamonds have reached the market. Of those appearing in 1945 probably 50% or more were fluorescent. The quality of artificial light may also affect the color of diamonds, seeming to improve some, though as a rule making most appear more yellowish.

In North America the Diamolite, a newly designed diamond-grading unit (see Plate A), which eliminates falsifying lights and reflections, is in use. It employs an artificial light filtered through a special daylight-blue filter and reveals the same variations in yellowish tinges visible in natural daylight. The unit provides a light source at all times uniform in an environment from which exterior reflections are largely eliminated—a source in which, by a special device, the body color of a diamond is more readily revealed.

#### CORUNDUM

Oxide of aluminium (alumina) ( $Al_2O_3$ ); Hexagonal (trigonal), ruby in six-sided prisms with basal plane and sapphire in 12-sided bi-pyramids. Sapphire crystals often barrel-shaped. Varieties: red (ruby), blue (sapphire), yellow, green, purple and colourless stones termed sapphire, with the colour as prefix. Star-stones (star ruby and star sapphire) show six-rayed star of light when cut en cabochon in the correct orientation, *i.e.*, with the base of the stone at right angles to the vertical crystal axis. Occasionally one or more of the rays are absent. Ruby star stones occur generally, in lighter or pale colors. Sapphire star stones are usually blue, grey-blue or

grey; very, very rarely violet or yellow. "Fancy sapphires" is a trade name applied in England to all colours of corundum except the red and blue. In the United States the term is sometimes incorrectly used to describe assorted lots of sapphires and other stones of many different species. Emery is an impure form of corundum used as an abrasive.

The hardness of corundum is 9, but rubies are in general very slightly softer than sapphires. Cleavage is not apparent, but there is a "false cleavage" known as *parting* and due to secondary twinning. *S.G.* = 4.00 (3.95—4.05). The lustre is vitreous and the refraction double. *R.I.* = 1.76—1.77, with a birefringence of 0.008. Dichroism is strong in ruby and blue sapphire and most fancy sapphires except the yellow. The whitish sheen seen in some rubies and sapphires is known as "silk." It is due to the presence of vast numbers of microscopically small included crystals or canals reflecting the light. When these canals are arranged in three directions parallel to the sides of the hexagonal form, stones cut en cabochon show the six-rayed star as mentioned above, *i.e.*, asterism.

Corundum occurs in gravels and clays derived from an impure limestone, recrystallization being caused by the influence of heat and pressure. Finest rubies are found in Burma (Mogok) while rubies from Thailand (Siam) are browner and contain more iron. Ceylon produces pale ruby which merge into the variety known as "pink sapphire." Fine sapphires are found in Thailand (Siam), Kashmir and Burma, while Ceylon produces good blue stones and many fancy colours. Blue sapphires from Australia are dark and inky and those from Montana (U.S.A.) have a distinctly metallic appearance. Rubies fluoresce strongly with a red glow when placed under ultra-violet light, due to chromic oxide ( $\text{Cr}_2\text{O}_3$ ), and it is to this oxide that the red colour of the stone is due. The blue of the sapphire is caused by a trace of iron and titanium. (The synthetic corundum will be discussed later.)

## BERYL

Silicate of aluminium and beryllium ( $\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$ ); Hexagonal, as hexagonal prisms. Varieties: grass-green (emerald), pale blue to bluish-green (aquamarine), yellow (golden beryl), pink (rose beryl or Morganite) and colourless. *H.* = about  $7\frac{3}{4}$ ; aquamarine is 8; emerald  $7\frac{1}{2}$ ; others variable. The cleavage is weak and indistinct. *S.G.* = about 2.7. Full range for the species is 2.65 to 2.85 (emerald 2.65 to 2.76). The lustre is vitreous and the refraction double. *R.I.* = 1.57-1.58, with birefringence of about 0.006. Dichroism is strong in the emerald and the blue aquamarine from Madagascar, but is weak in the other varieties.

Emerald is rarely found which is not badly flawed, while the aquamarine is found in large crystals perfectly water clear. The major occurrences of emerald are in Colombia (S. America), where it is found in veins of calcite; in the Ural Mountains (Russia); Egypt, in a mica shist; in Brazil; in South Africa (Transvaal) and in Australia. Aquamarines are found in Brazil, California, North Carolina, Maine, Madagascar and Ceylon. A remarkable yellow beryl is found in South-West Africa which is radio-active. Emerald has been made synthetically, but the few stones which have been marketed are not of very fine color, cost as much as genuine emeralds of the same quality, and can be rather easily identified as described in the next chapter.

## TOPAZ

Fluo-silicate of aluminium ( $\text{Al}_2(\text{F}, \text{OH})_2\text{SiO}_4$ ); Orthorhombic crystals prismatic in habit, prism faces vertically striated, and capped with pyramids. Varieties: colourless (white topaz) and colours from yellow to brown are common. Blue to green, which resembles aquamarine, occurs. Red and pink colours are rarely found naturally, the pink topaz on the market is the brown variety treated with heat which turns the stone a lovely rose pink (or if incorrectly heated a salmon colour). This is termed

"pinking."  $H. = 8$ . Topaz has a very strong cleavage at right angles to the length of the crystal. This is termed *basal* cleavage.  $S.G. =$  average 3.53 (full range 3.50 to 3.60). The lustre is vitreous and the refraction double.  $R.I. = 1.62-1.63$ , with a birefringence of 0.01. The dichroism is distinct in well-coloured stones (strong in pink "fired" topaz). The principal localities for topaz are in Brazil, Russia and Ceylon. Lesser occurrences are in Saxony and Japan, while recent finds have been in South-West Africa, Northern Nigeria and Southern Rhodesia. Topaz is also found in Scotland and in the Mourne Mountains in Ireland. Principal North American localities are California, Colorado, Maine, Texas and Utah. The name "topaz" has been used indiscriminately for many yellow stones, and in particular the yellow quartz (citrine). Almost all of the yellow brown or reddish stones sold in North America as topaz are, in fact, yellow crystalline quartz of the variety known as citrine. Only those jewelers who are both better informed and more conscientious sell the latter as citrine or topaz quartz. Others call it topaz, "precious topaz" or "Brazilian topaz."

## SPINEL

Magnesium aluminate ( $MgAl_2O_4$ ); Cubic, commonly as octahedra (8-sided). Twins common, particularly the type known as the "spinel twin." Varieties: reds, sometimes mis-called "Ruby Spinel," pale reds are known as "Balas Ruby," yellowish-red as Rubicelle ("Flame spinel"), purples, blues, both light and dark, greens and black. The dark green is known as chlorospinel and the black as pleonaste or ceylonite.  $H. = 8$ . Spinel shows practically no cleavage.  $S.G. = 3.60$ . The lustre is vitreous and the refraction is single.  $R.I. = 1.72$ . Spinel is generally found in association with ruby in Burma and Thailand (Siam) and in the gem gravels of Ceylon. Some spinels have been reported which reveal four-rayed stars or both four and six-rayed stars. One seven-rayed star spinel is known. Synthetic spinel, described in the next chapter, is commonly cut as gemstones.

## GARNET

This name is applied to a group of gemstones which crystallize in the cubic system with ball-like habit (dode-

cahedra and trapezohedra) and which have a definite relation between their chemical compositions. All consist of a double silicate in which one of the metals may be calcium, iron, magnesium or manganese while the others may be aluminium, iron or chromium.

Varieties:—

*Grossular*. Calcium aluminium silicate ( $\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$ );  $H. = 6\frac{1}{2}$  to 7;  $S.G. = 3.55$  to 3.67;  $R.I. = 1.74$ ; colours are brownish-yellow (Cinnamon stone) and reddish-orange (hyacinth garnet), both known as *hessonite*. A massive green variety which comes from South America is known as "Transvaal jade." The most important locality for hessonite is Ceylon. Known in the United States as grossularite, a green variety from Oregon sufficiently resembles green jade to be sold as such. Also a white jade-like variety, as well as hessonite, has been found in California.

*Pyrope*. Magnesium aluminium silicate ( $\text{Mg}_3\text{Al}_2(\text{SiO}_4)_3$ );  $H. = 7\frac{1}{2}$ ;  $S.G. = 3.68$  to 3.84;  $R.I. = 1.74$  to 1.77; colour = blood-red; Localities = South Africa (in association with diamond), Bohemia, Arizona, etc. Pyropes of high S.G. and R.I. merge into almandine.

*Almandine*. Iron aluminium silicate ( $\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$ );  $H. = 7\frac{1}{2}$ ;  $S.G. = 3.85$  to 4.20;  $R.I. = 1.77$  to 1.82; Colours are deep red, violet-red to black; Localities for almandine are India, Ceylon, Australia and North and South America. Almandine exhibits a characteristic absorption spectrum of three strong bands, one in the yellow and two in the green. Some almandine shows 4 or 6-rayed asterism.

*Andradite*. Calcium iron silicate ( $\text{Ca}_3\text{Fe}_2(\text{SiO}_4)_3$ );  $H. = 6\frac{1}{2}$ ;  $S.G. = 3.84$ .  $R.I. = 1.89$ ; Colours = green (demantoid) and yellow (topazolite). Localities = Russia and Saxony. Andradite shows considerable "fire," greater even than that of the diamond. Demantoid shows an absorption spectrum of a band in the violet.

*Spessartite*. Manganese aluminium silicate ( $\text{Mn}_3\text{Al}_2(\text{SiO}_4)_3$ );  $H. = 7\frac{1}{4}$ ;  $S.G. = 3.90$  to 4.20;  $R.I. = 1.79$  to 1.81; Colour = orange-red and brown; Localities = Bavaria, Ceylon,

Tyrol, Virginia and Nevada.

The calcium chromium silicate garnet known as *Uvarovite* has not been found in pieces (crystals) large enough to cut, if it were it would make an attractive green stone. *Rhodolite* is the name applied to a violet variety which in composition lies between pyrope and almandine, with *S.G.* = 3.84 and *R.I.* = 1.76. It is found in Macon Co., N. Carolina. When, as in the case of garnet, one element in the chemical composition of a mineral is replaced by another element having the same valency, and without sensibly altering the structure and form of the crystal the phenomenon is termed *isomorphous replacement*.

#### TOURMALINE

A complex boro-silicate of aluminium; Hexagonal(trigonal) with prismatic habit. The crystals are roughly triangular in section capped with pyramids. The opposite ends of the crystal have different terminations (*hemimorphism*) and they are deeply striated along their length; Varieties: red (rubellite), blue (indicolite), green, yellow, violet-red; *H.* =  $7\frac{1}{4}$ ; *S.G.* = 3.08; *R.I.* = 1.62-1.64; the lustre is vitreous and the refraction double, about 0.018. Dichroism is strong; Localities = Brazil, Siberia, Madagascar, in the Ceylon gem gravels, Maine and California. A fibrous form gives a cat's-eye effect.

#### PERIDOT (THE OLIVINE OF SCIENCE)

Silicate of magnesium and iron ( $\text{Mg, Fe}_2\text{SiO}_4$ ); Orthorhombic with prismatic habit (crystals are often flattened); Varieties: yellow, greenish-yellow, bottle-green, leaf-green and brown. *H.* =  $6\frac{1}{2}$  to 7; *S.G.* = 3.40; Lustre somewhat oily and refraction double (0.036); *R.I.* = 1.66-1.70. The dichroism is distinct; Localities = Island of St. John in the Red Sea, Burma, Australia, Norway and New Mexico.

#### ZIRCON

Silicate of zirconium ( $\text{ZrSiO}_4$ ); Tetragonal, common form is a four-sided prism terminated at each end with a four-sided pyramid; Varieties: colourless, yellow and pale shades are termed *jargoon*, reds and reddish-browns *jacinth*, greens and



many fancy colours. The popular blue and orange colours and the colourless stones now on the market are "fired" or, as it is sometimes termed, *heat treated*. The brown and hyacinth colours from Indo-China are the only crystals which are usable for this purpose. Zircon is remarkable for its wide range of S.G. and R.I., there is, in fact, not one zircon but three zircons, *viz.*, the (*a*) or low type; the (*b*) or high type; and (*c*) the intermediate type.

(*a*) *Low type*.

Nearly amorphous, only found as rolled pebbles; *H.* = 6; *S.G.* = 3.94 to 4.40; *R.I.* = 1.78 to 1.84. Refraction; very nearly single; Dichroism none; Colours = green or greenish brown.

(*b*) *High type*.

Definite tetragonal crystals. *H.* =  $7\frac{1}{4}$ ; *S.G.* = 4.65 to 4.71; the refraction is double and large in amount; *R.I.* = 1.92-1.98; Dichroism weak, except in the heat-treated bluestones; Colours = colourless, red, blue, honey-yellow and light green.

(*c*) *Intermediate type*.

*S.G.* = 4.10 to 4.65; *R.I.* = 1.84-1.85 and higher. On heating this type it is converted to the high type with increase not only of S.G. and R.I., but also amount of double refraction.

Type (*a*) is understood to be composed of amorphous silica ( $\text{SiO}_2$ ) and nearly amorphous zirconia ( $\text{ZrO}_2$ ) while the high type (type (*b*)) is completely crystallized zirconium silicate. The (*c*) being intermediate to either the application of heat causes recombination of the oxides and silicate to the completely stable crystalline form. Zircon exhibits in many cases a characteristic absorption spectrum of fine lines, due to traces of uranium. The localities in which this gemstone is found are Ceylon, Burma, Thailand (Siam), Indo-China, Australia, South Africa and France.

#### CHRYSOBERYL

Beryllium aluminate ( $\text{BeAl}_2\text{O}_4$ ); Orthorhombic, flattened twin crystals common, sometimes giving a pseudohexagonal



form; Varieties: pale yellow to greenish-yellow, dark green (alexandrite) and honey-yellow to brownish-green with chatoyant effect (cat's-eye). Distinct cleavage in one direction only;  $H. = 8\frac{1}{2}$ ;  $S.G. = 3.72$ . Refraction is double and the dichroism while strong in alexandrite is weak in the other varieties.  $R.I. = 1.75-1.76$ . Alexandrite appears green in daylight and red in artificial light. Localities = Brazil (yellows), Ural Mountains, Russia (alexandrite), Ceylon (cat's-eyes and alexandrite).

#### QUARTZ

Oxide of silicon (silica) ( $SiO_2$ ) may be divided into two groups, the crystalline and the cryptocrystalline.

##### *Crystalline type.*

Hexagonal (trigonal), prismatic habit; Varieties: colourless (rock crystal), brown (smoky quartz), white (milky quartz), yellow to reddish-brown (carnelian), yellow (citrine), purple (amethyst), pink (rose quartz), green (prase), green chatoyant (cat's-eye), yellow chatoyant (tiger's-eye), blue (sardonyx), brown, yellow, red or green with spangles of mica (aventurine), colourless with acicular inclusions (rutiled quartz or Venus' hair stone);  $H. = 7$ .  $S.G. = 2.65$ . Lustre is vitreous and refraction double while the dichroism is weak;  $R.I. = 1.54-1.55$ . Smoky quartz when heated reddish-brown and amethyst so treated turns to a yellow citrine. Rose quartz is noteworthy in never being found as crystals, only massive; "Tiger's-eye" is often termed *crocidolite*, which is the name applied to an asbestos, and it is the replacement by silica of the fibres of asbestos which give the "tiger's-eye." Quartz is found abundantly all over the world, the most important localities for gem material are Brazil, Ceylon, Russia, Madagascar, Japan, Scotland, South Dakota, Colorado, Arizona, etc. (rock crystal, citrine and amethyst), India and China (aventurine) and Griqualand, S.W. Africa (crocidolite).

##### *Crypto-crystalline type.*

Composed of a mass of minute crystalline fibres. Chalcedony is the general term used for this type of quartz, variety names being given to the different colours, *viz.*, *carnelian*, translucent flesh-red; *sard*, brownish-red; *chrysoprase*, trans-

lucent apple-green; *bloodstone*, dark green with scattered spots of red jasper; *agates* and *onyx* are banded varieties and *jasper* is an impure variety.  $H. = 7$ ;  $S.G. = 2.58$  to  $2.64$  (slightly lower than crystalline quartz);  $R.I. = 1.53-1.54$  (likewise slightly lower). Chalcedony is somewhat porous and, therefore, can be stained in various colours. Chalcedony is very widespread, the main localities are Brazil, Madagascar, Uruguay, Oregon, California, Texas, Wyoming, etc. Moss agate, clear chalcedony containing inclusions of manganese in the form of ferns, is a type commonly found in India.

#### OPAL

Hydrated silica ( $\text{SiO}_2 \cdot x\text{H}_2\text{O}$ ). Non-crystalline, hence amorphous, a solidified jelly. Varieties are *black opal* and *white opal*, both of which show characteristic opalescent colours due to interference of light, as has been explained. *Fire opal* is transparent to translucent and of reddish-yellow colour.  $H. = 5\frac{1}{2}$  to  $6\frac{1}{2}$ ;  $S.G. = 2.1$ . Refraction single and  $R.I. = 1.45$ . The old theory that the interference of light producing the play of colour in opal was due to thin films of secondary opal filling fissures in the main mass or original opal, has recently been modified by a theory that the thin films are due to lamellar twinning in a silica pseudomorph of calcite crystals. Opal is found in Hungary, Australia (black and white), Mexico (fire opal), Nevada and Idaho (an inferior black opal).

#### TURQUOISE

Hydrous phosphate of aluminium coloured by a copper compound; Triclinic (crypto-crystalline) as nodules or concretionary masses and veins. Colours, blue and green. Turquoise is opaque and valued for its body colour only.  $H. = 6$ ;  $S.G. = 2.6$  to  $2.8$ ;  $R.I.$  about  $1.62$ . Lustre is waxy. Best turquoise comes from Persia, other localities being Sinai Peninsula, Egypt, Tibet, New Mexico, Arizona, Nevada, California and Texas. When turquoise is cut with some of the limonite matrix it is known as *turquoise matrix*.

#### SPODUMENE

Silicate of aluminium and lithium ( $\text{LiAl}(\text{SiO}_3)_2$ ); Mono-

clinic with prismatic habit; Varieties: yellow, green (hiddenite) and lilac (kunzite).  $H. = 6\frac{1}{2}$ ;  $S.G. = 3.18$ . Cleavage perfect in two directions, lustre vitreous and refraction double.  $R.I. = 1.66-1.68$  and exhibits strong dichroism. Localities are California and Madagascar (kunzite and yellow), N. Carolina (hiddenite).

## SPHENE

Silicate and titanate of calcium ( $CaTiSiO_5$ ); Monoclinic; Colour varieties: green, yellow and brownish-yellow.  $H. = 5\frac{1}{2}$ ;  $S.G. = 3.53$ . Lustre adamantine, refraction double and dichroism very strong.  $R.I. = 1.91-2.06$ . Spene exhibits greater "fire" than the diamond. Found in Ceylon and Switzerland.

## FELDSPAR

Silicate of aluminium with another metal which may be either potassium, sodium or calcium. Two groups: (a) orthoclase = potassium feldspar; (b) plagioclase = sodium and calcium feldspars. Orthoclase crystallizes in the monoclinic system and plagioclase in the triclinic system. Varieties: clear colourless with milky sheen due to lamellar twinning (moonstone), and yellow are both orthoclase. Another potash feldspar is the opaque green variety termed *microline* or "Amazon-stone." Sunstone, a reddish and spangled variety, and Labradorite, which shows a play of colour are plagioclase feldspars.  $H. = 6$  to  $7$ ;  $S.G. = 2.5$  to  $2.7$ . Refraction double with  $R.I. = 1.52-1.53$ . Localities = Moonstone, at Ceylon, yellow orthoclase, at Madagascar, sunstone, Norway, labradorite, Canada and Labrador, and Amazon-stone, Pennsylvania and Virginia.

## JADE

Two distinct minerals are known under this name.

*Nephrite*.

A tough compact fibrous mineral varying in colour from white to dark green.  $H. = 6$  to  $6\frac{1}{2}$ ;  $S.G. = 2.95$  to  $3.1$ . Used for carvings and found in New Zealand, Turkestan, Russia and Wyoming.

*Jadeite.*

The most highly prized of the two "jades" is a similarly compact mineral showing a range of colour from white to green and also brown, red, mauve, etc. It is the material most prized by the Chinese for their carvings. *H.* =  $6\frac{1}{2}$  to 7; *S.G.* = 3.3 to 3.5. Jadeite is found in Burma.

## LAPIS LAZULI

Chief character is its colour, a uniform dark blue of great intensity (often containing glistening flakes of yellow iron pyrites). It is really a mixture of different minerals (hauynite, lazurite and sodalite) grains of which are in a matrix of calcite. *S.G.* = 2.7 to 2.9. Localities are Afghanistan, Chile, Siberia and California.

**Test Questions**

40. What test for refractive index can be carried out with an ordinary microscope?
41. How many nicol prisms are there in a petrological microscope?
42. A green stone is placed on the rotatable stage of a petrological microscope with its nicols set in the crossed position. On the stage being turned through a full circle the field as seen through the eyepiece remained dark. Suggest what the stone is likely to be.
43. What is anomalous double refraction due to in general?
44. Name three gems which have strong cleavage, three which have strong "fire" and three with a hardness greater than topaz.
45. A red stone is thought to be an almandine garnet. With the sole equipment of a dichroscope, a pocket spectroscope and a bottle of methylene iodide, would you be able to identify positively and, if so, state how?

## CHAPTER X

### SYNTHETIC GEMS

SINCE the dawn of chemical science as an exact art, in the eighteenth century, attempts have been made to produce exact copies of the minerals and crystals found in God's good earth. The production of those minerals which are prized by man for their rarity, and by woman as a foil to her own rare charm and beauty, has acted as a spur to the man of science in his varied attempts to bridle nature, and his success in this direction forms the subject of these few notes.

While, unknown to the average jeweller and layman, for many years experiments on the synthesis of gemstones have been carried out in laboratories throughout the world, at the present time it may be safely stated that every gemstone, excepting perhaps diamond itself, has been made synthetically. There is, however, the consideration that to be of commercial importance the man-made gem must be cheaper to produce than the natural mined stone and in crystals large enough for cutting: *e.g.*, the mineral quartz ( $\text{SiO}_2$ ) has been successfully synthetically produced for many years, but quartz, even in the more highly prized variety—amethyst, is so abundant in nature that the cost of making in a laboratory is far greater than the value it would have in the market.

While this remains true of most gem materials, with the so-called precious stones, that is, the diamond, the ruby, the emerald and the sapphire, the economic conditions give every encouragement for the synthetic production on a commercial basis. It is in the main the commercially produced synthetic gems which concern the jeweler and practical gemologist.

With its simple chemical composition (carbon = C.), diamond should apparently be the easiest mineral to produce synthetically, but in the case of this gem its synthesis is well-

nigh impossible owing to the fact that carbon burns at a temperature less than its melting point. Moreover, the stable form of carbon is the common mineral graphite. Many attempts have been made to make diamond, and by many different means, but in all cases the results were too small to have any bearing commercially, too small in fact for a really accurate identification, hence, all those reported syntheses are suspect.

The first attempt to make diamond was that of J. B. Hannay, a Glasgow chemist, who, in 1880, heated in a strong sealed cylinder a mixture of hydrocarbons and the rare element lithium. The resulting hard black mass was found to contain a few minute crystals whose size precluded any attempt, with the means then available, accurately to identify them. Henri Moissan, whose experiments have assumed classic importance, heated a mixture of iron and sugar carbon contained in a carbon crucible to about  $4,000^{\circ}$  C. in an electric furnace. The iron melted and became saturated with carbon. The mixture was rapidly cooled by being placed in molten lead. This formed a crust on the outside with the more slowly solidifying material in the centre still molten. Iron, like ice, expands on assuming the solid state from the liquid, thus, when the centre does solidify it does so under great pressure. The iron was laboriously dissolved out by warm aqua regia (a mixture of hydrochloric and nitric acids) and the residue examined. This was found to consist in the main of carbon in the form of graphite and a few small and distorted crystals which were assumed, with the aid of tests then available, to be diamond. Moissan, who carried out these experiments in 1893, was led to follow this line of investigation by the discovery of diamond in iron meteorites. That diamonds were produced by these experiments is still open to question.

Other methods tried by many different experimenters, using chemical, thermal and electrical action, have also failed to give much in the way of convincing results, nor has the process described and patented by a group of Austrian

scientists in 1931, by a method involving an alternate decrease and increase of pressure, appeared to have produced results, at least they were not ready to demonstrate their work before the impartiality of English mineralogists. Likewise the more recent work of Hershey, in America, seems to have been thoroughly disproved.<sup>1</sup> That diamond has been made seems debatable, whether it ever will be is another matter; clairvoyancy is not an aspect of gemology. There is, however, a world of difference between an academic production of minute crystals and gems for the jeweller, who can rest assured that no diamonds synthetically made can come his way for a generation or two.

With the corundum gems—ruby and sapphire, considerable success has been obtained. As early as 1837 the French chemist, Marc A. A. Gaudin, produced a few tiny flakes of crystallized alumina, while E. Fremy and C. Feil, in 1877, produced similar and larger plate-like crystals of ruby. In 1885 a number of rubies came upon the jewellery market and were accepted as natural stones. Soon their genuineness was questioned, and it later transpired that these stones had been made by the direct fusion of small fragments of real ruby, with a small piece of bichromate of potash to give the colour, in the flame of an oxy-hydrogen blowpipe. These stones, which had all the optical and physical characters of true ruby, were seen, when viewed under a lens, to contain many gas bubbles, often irregularly arranged and giving the stone a cloudy effect. They often contain flaws due to the rapid cooling, and some show the characteristic whirl striæ like that seen in badly annealed glass. Later, in 1895, Michaud improved the method by heating a large fragment of natural ruby at about 1,800° C. in a revolving platinum crucible and slowly adding smaller chips, sometimes with a little potassium bichromate to increase the colour. These gems may be said to be a form of reconstruction, and are known as *reconstructed rubies*. Unfortunately, this name has persisted in the trade, and is used indiscriminately for all true synthetic stones, an error which all jewelers should co-operate to stamp out.

<sup>1</sup> "Supposed Synthetic Diamonds Tested," *Gems and Gemology* (Los Angeles), Vol. II, 1938, pp. 195-198.



After some years of research the French chemist, Auguste Verneuil, discovered a method whereby true synthetic corundum of all colours and of large size could be made.

He constructed a special form of inverted oxy-hydrogen blowpipe or *chalumeau* (in practice coal gas is used in place of the hydrogen), and in 1904 published a short account of his experiments. The apparatus Verneuil used consists of a vertical blowpipe (Fig. 41) whose upper part is in the form of a large chamber C, in which is suspended a sieve P containing the finely powdered mixture of alumina and chromium oxide (for ruby). The wire by which the sieve is suspended penetrates the lid of the chamber and terminates in a small disc E. The oxygen enters the blowpipe by the opening O in the lid of the upper chamber so that when the disc is tapped the powder is shaken out of the sieve and carried along to the flame on the current of oxygen. The support R upon which the molten mass grows, consists of a rod of alumina which is fastened to an iron arm S which is so constructed that it can be moved in a vertical direction, backwards and forwards and also laterally in order that the mass may be kept in the hottest part of the flame.

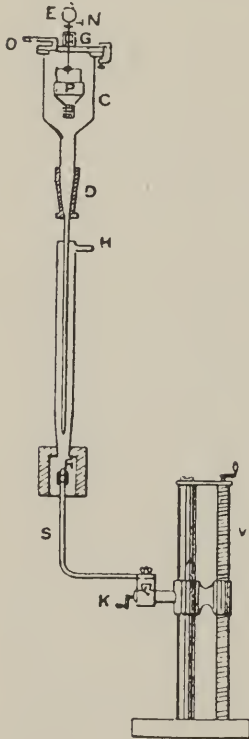


FIG. 41.—Section of Verneuil blowpipe

The hydrogen (coal gas) is allowed to enter through the opening H.

The clear mass which grows on the support is known as a *boule* or *birne*,<sup>1</sup> and is pear-shape in form, the stalk being the part attached to the stand. The top of the mass is seen to be

<sup>1</sup> Small rods of synthetic corundum have been developed recently by Linde Air Products Co., New York.

covered with a reticulated "froth" which under magnification is seen to consist of a mass of crystal plates. The actual boule is one single crystal individual, but has a line of weakness, due to a twin plane, which causes the boule to split in two pieces vertically from top to bottom when struck by a blow or when the stalk is nipped off with pliers.

Stones cut from these boules have all the physical and optical properties of a natural stone, that is, they have the same specific gravity and refractive indices as natural corundum, and they also exhibit dichroism. They are made in all the colours in which natural stones are found. If only pure alumina is used, "white" sapphire is made, the red of ruby is obtained by the addition to the alumina of about 2.5 per cent of chromic oxide, while for sapphire the oxides of titanium and iron are used as the colouring oxides, and other oxides are used for other colours.

As has been mentioned, these synthetic corundums are made in many different colours, and it may be of some value if a list of colours and the gems they simulate is appended:—

Red	...	...	...	Ruby.
Dark Red	...	...	...	Garnet.
Rose red	...	...	...	Pink Sapphire, "Fired" Topaz, etc.
Lilac	...	...	...	Kunzite.
Purple	...	...	...	Amethyst, Violet Sapphire.
Yellow	...	...	...	Yellow Sapphire, Topaz, etc.
Orange	...	...	...	Yellow Sapphire.
Orange red	...	...	...	Garnet, Zircon, Fire Opal, etc.
Blue	...	...	...	Sapphire.
Green	...	...	...	Sapphire, Emerald, etc.
Brown	...	...	...	Topaz.
Green (with change)	...	...	...	Alexandrite.

Despite the fact that synthetic corundum has almost every character of the natural gem corundum there are yet structural differences which allow the discrimination between the natural and man-made gems. These differences, sometimes

easily visible with the aid of a low power hand lens, are in general only observed by the aid of the more powerful and all-seeing eye of the microscope. It may be as well to recall that in order to "get into" the stone it may be necessary to immerse it in highly refractive oil, such as monobromonaphthalene. A natural stone almost invariably shows some signs of its natural origin, such as straight lines crossing one another at an angle of  $60^\circ$  or crystal inclusions, which always show straight sides. The synthetic corundum shows curved lines or bands of growth and often round gas bubbles which, if small, may appear as clouds of dust spots. The photomicrographs show the difference in the two structures better than words can describe. Recent improvements in production of the boules, mainly that of rotating the boule during its formation, clears the boule of most of the bubbles. In coloured material the curved lines are most characteristic. The natural stone invariably shows the hall mark of its natural origin, in fact, it is extremely rare to find a natural corundum which does not show some characteristic sign; either in the way of large crystal inclusions, small needle-like crystals which are oriented at  $60^\circ$ , or straight lines or bands. The synthetic corundums of to-day are comparatively *clean*, and the large gas bubbles seen in the earlier types are absent, although the curved lines of the growth of the boule are generally visible if care and patience is taken with the examination. (See Plates I and II.)

After Verneuil's initial success with the production of the synthetic red corundum, an attempt was made to make the blue sapphire. It was at that time thought that cobalt was the metal which gave the blue colour to this variety of corundum, hence cobalt was used with the alumina in the first experiments. The resultant boule was found to be patchy in colour, which, indeed, scarcely simulated the colour of the natural sapphire. In order to make the colour more uniform the experimenters added magnesia to the alumina and cobalt. The result was a good clean stone of uniform colour, which had a characteristic "Reckitt's blue"

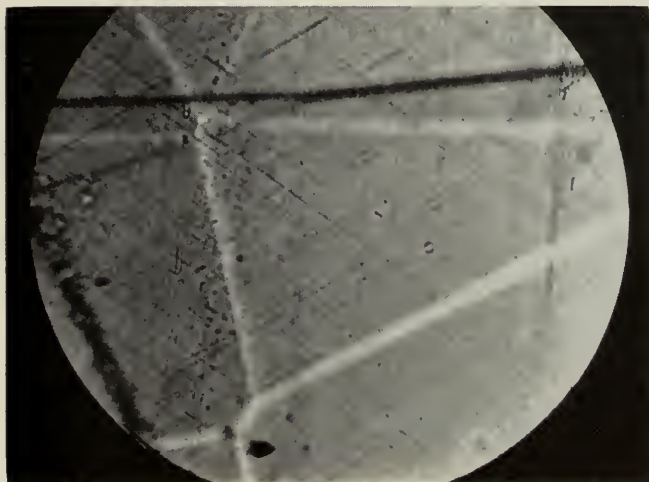
PLATE I



A

CRYSTAL INCLUSIONS IN A CEYLON SAPPHIRE

Photo: S. R. Bach



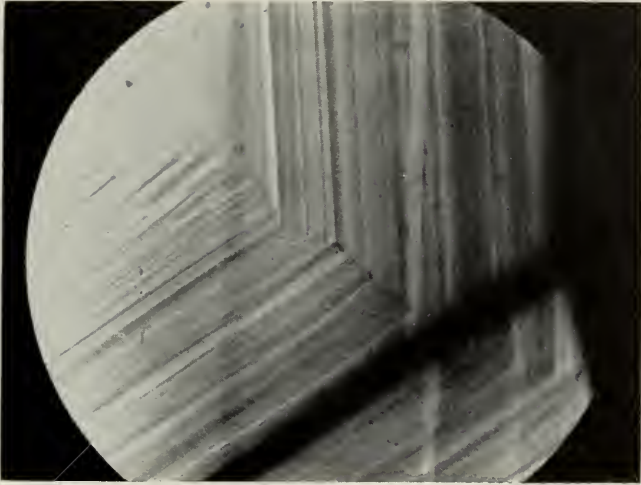
B

FINE RUTILE NEEDLES ("SILK") IN A GENUINE CEYLON RUBY

Photo: Gemological Institute of America



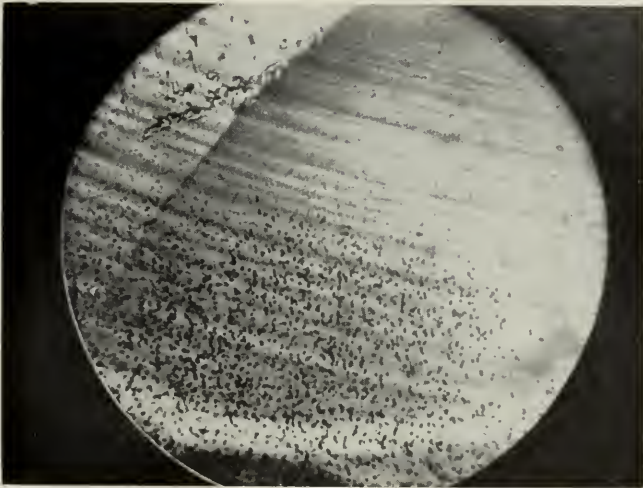
PLATE II



A

HEXAGONAL ZONING IN A GENUINE SAPPHIRE

Photo: Edward Gubelin, C.G.



B

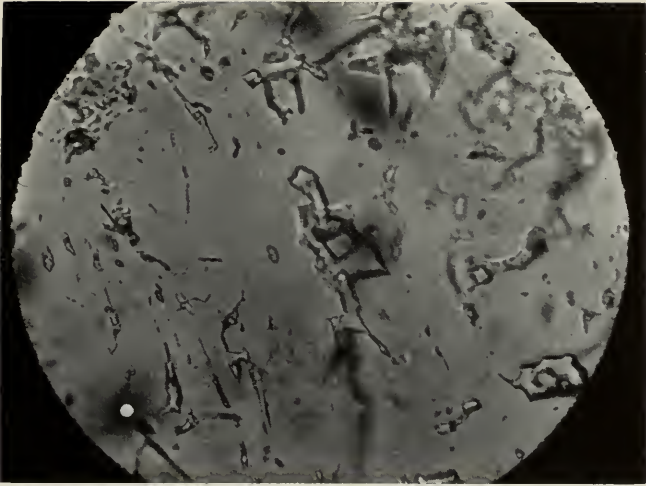
CURVED COLOR BANDS AND MANY SMALL GAS BUBBLES  
IN A SYNTHETIC SAPPHIRE

Photo: Gemological Institute of America





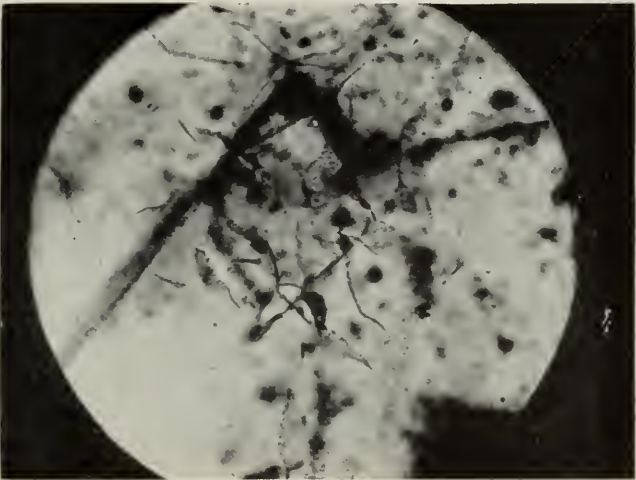
PLATE III



A

INCLUSIONS IN A GENUINE EMERALD

Photo: Edward Gubelin, C.G.



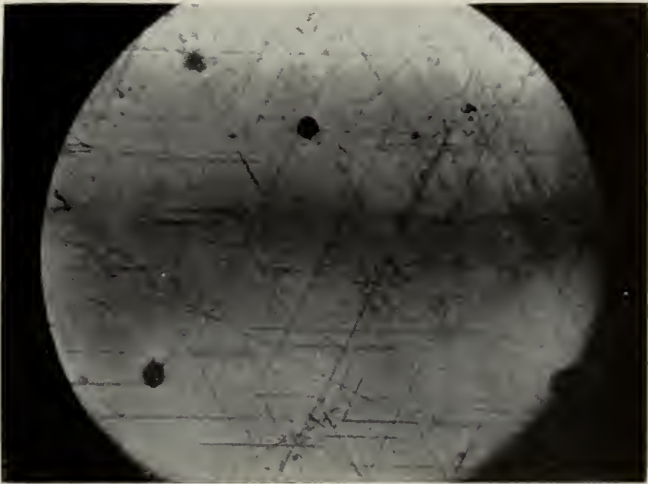
B

WISP-LIKE INCLUSIONS IN SYNTHETIC EMERALD

Photo: Gemological Institute of America



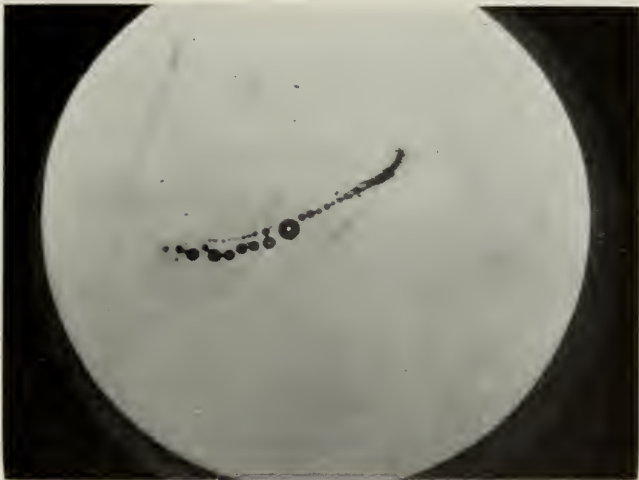
PLATE IV



A

NEEDLE-LIKE INCLUDED CRYSTALS AND BUBBLES IN A DOUBLET

Photo: Gemological Institute of America



B

CHAIN OF BUBBLES SUCH AS SEEN IN GLASS  
IMITATION OR SYNTHETIC STONE

Photo: Edward Gubelin, C.G.



rather than the colour of the natural blue of the sapphire. This was not all, for on examination the stone was found to be a spinel and not a corundum.

At the time, about 1907, there was no apparent necessity for the production of synthetic spinel. Spinel, even in the red variety, had no great value as a gemstone. In the last fifteen years, those years in which more regard has been paid to such semi-precious stones as blue zircon, aquamarine and pink topaz, etc., the synthesis of spinel by the Verneuil method has taken on a new importance by the facility with which the shades of these semi-precious stones may be obtained in the synthetic spinel.

The boule obtained by the Verneuil synthetic spinel, although pear-shape in form like the similarly made corundum, has one difference in that the boules have flattened sides, the sides of a cube and the outward expression of the crystal structure (the synthetic corundum boule has been seen to show the hexagonal form, but this is very rare). Likewise the spinel differs from that of the corundum in that in many cases, particularly in the new colours, the molecular ratio is in general  $\text{MgO} \cdot 2\text{Al}_2\text{O}_3$ , whereas normal spinel is  $\text{MgO} \cdot \text{Al}_2\text{O}_3$ . This difference is manifest in a slightly higher refractive index, *i.e.*, 1.73 as against 1.72 for the natural stones. The specific gravity is also affected and is slightly higher, about 3.63.

Unlike synthetic corundum the synthetic spinel rarely shows curved bands or striæ and is remarkably free from gas bubbles. Their detection is easy, however, for the spinels are rarely made in colours reminiscent of the natural spinel. As before mentioned, all stones with a higher R.I. than the natural spinel must be suspect. The types of blue spinels made to imitate the blue zircon and the aquamarine are coloured with cobalt which causes the stone to assume a red or orange hue when it is viewed through the emerald filter; the natural blue zircon and the aquamarine appear green when so viewed.

Synthetic spinel may be: Red (rarely); pale blue; dark blue; yellow and yellow green; colourless; rose-red; deep green; and green with colour change (imitating alexandrite).

Owing to its complex chemical composition, and the facility with which the molecules of alumina, beryllia and silica can assume different proportions and hence many different minerals, the synthesis of emerald has presented countless difficulties which have only been overcome during the past few years.

Early experiments on the *reconstruction* of the green beryl on the lines of the reconstructed ruby failed. The resulting product being a glass and not a crystal. Emeralds of minute size had been made in the laboratories of experimental chemists for some time past but these had no commercial significance. In 1934-35 the German Dye Trust (I.G. Farbenindustrie) laboratories at their Bitterfeld works produced true synthetic emerald. The experimental work being carried out by Dr. Jaeger and Dr. Espig. The amount of double refraction of these synthetics was considerably less than that of the natural stone, being 0.001 to 0.003 as against 0.005 to 0.007 for the natural gem. The specific gravity was also somewhat lower, being between the limits 2.64 and 2.66 (natural emerald = 2.67 to 2.77).

Unlike the synthetic corundum and spinel just discussed, the synthetic emerald is not made on a hydrogen/coal-gas blowpipe, but, as far as is known of the process, is grown from a fusion in the form of hexagonal crystals, the form that the emerald assumes in nature. The stones which appeared before World War II are small, no large cut stones have ever been reported, none more than a carat in weight, and they have, as far as can be estimated with the small number so far examined by experts competent to judge, certain characteristic signs which make possible their identification.

The colour of these stones was good but under the microscope certain wisp-like cracks are seen which do not appear to be present in the natural stone. (See Plate III.)

A private California laboratory also produces and sells synthetic emeralds. Their price is out of proportion to that of

genuine stones of like size and quality.

Cut stones have weighed usually under a carat, never over three; color, not comparable to that of fine genuine emerald is usually evenly distributed and constant in most specimens. Refractive index and specific gravity, a little lower than in genuine emeralds, is sufficiently close to eliminate these tests to distinguish synthetic from genuine.

Characteristics of American synthetic emeralds: wisplike inclusions usually in groups seemingly in the center of the stone, elongated parallel to its length, or extending in the same direction as the vertical axis. Some specimens also exhibit straight parallel lines at right angles to these; others show small irregularly shaped inclusions, probably particles of coloring matter, which though greenish in color, appear black under 10x to 40x magnification. Well illuminated on the Diamond-scope at 22.5x, wisps appear to be made up of liquid inclusions similar to those in Ceylon sapphires. Bubbles or curved striae do not appear.

#### **Recapitulation**

Diamond is not made synthetically.

Corundum and Spinel only species made for commercial purposes, and on oxy-hydrogen blowpipe. Emerald has recently been made by an undisclosed process but has no commercial significance at the moment.

A synthetic gem has all the characters of a real gem except internal structure.

Synthetic corundums generally show characteristic curved lines of growth and gas bubbles, while synthetic spinels are generally clear.

Synthetic corundum is generally made to imitate the real stone of the same species, whereas the synthetic spinels are made in colours to imitate stones of another species.

Blue synthetic spinels show red or orange when viewed through the Chelsea Colour Filter.

#### **Test Questions**

46. What gem of blue colour has a refractive index of 1.72 and a specific gravity of 3.61? Is this stone singly or doubly refracting?

47. What gems are found in Thailand and Afghanistan?

48. What gemstones come in the group of minerals known as feldspars?

49. Which of the following named gemstones has the greatest amount of birefringence: Beryl; Spinel; Topaz; Tourmaline?

50. What is a characteristic peculiarity of the crystals of tourmaline?

51. What is the usual name applied by jewellers to the olivine of science?



CHAPTER XI  
IMITATION GEMS

IN the last chapter there was discussed those gems which are made by man, which have the same chemical composition and similar physical and optical properties to the natural stones. The next types of counterfeit to come under review are those artificial stones which simulate the real gem in colour and appearance alone. Unlike the synthetic gems, which are a product of the scientific ingenuity of the nineteenth and twentieth century chemist, these imitation gems have been produced from mediæval and even ancient times, for, according to Flinders Petrie, glass was made in Egypt as early as 1,600 B.C.

GLASS

Probably the most important imitation gem is that which is made of glass. Glass is a melt consisting in the main of sand (silica =  $\text{SiO}_2$ ) and either soda or potash with the addition of other oxides (such as the oxides of barium, zinc, aluminium, thallium, etc.) and the colouring is produced by small amounts of other metallic oxides, certain elements and chemical compounds. Glass may best be defined as a mixture of silicates. It is amorphous, that is, non-crystalline; thus its physical and optical properties are the same in all directions. Glass, owing to the variable nature of its constituents, may therefore have an immense range of specific gravity and refractive index, although they do have some relation one to another. If, however, a glass has a definite chemical composition its constants will have a fixed value. This is so in the case of quartz glass and beryl glass, which are crystal quartz or beryl fused in a furnace, thus losing their crystalline structure and becoming a glass. The R.I. and S.G. of fused quartz (silica glass) are 1.46 and 2.21 respectively, while those

of beryl glass are 1.525 and 2.40. These, as will be seen, are somewhat lower than for the crystal, and what is more important, the quartz and beryl glasses are singly refractive to light.

There are two main divisions into which glass may be divided, and these are known as *Crown (window or bottle) glass* and *Flint or lead glass*. Crown glass may be generally stated to be composed of silica, potash or soda, and lime. It has a range of refractive index from about 1.44 to 1.53, and

	Refractive index.	Specific gravity.
Opal... ..	1.44 to 1.46	2.07 to 2.15
Titanium-iron ...	1.47 to 1.49	2.40 to 2.52
Borosilicate. . .	1.50	2.36
Calcium ... ..	1.52 to 1.54	2.53 to 2.57
Calcium-iron ...	1.57 to 1.59	2.66 to 2.75
Flint (Lead).. .	1.58 to 1.68	3.15 to 4.15

*The above Table, based on the work of Mr. F. A. Bannister, M.A., is the range most usually found for the different types of glasses in use as gem counterfeits. The single figure given for the borosilicate glass must be taken as a mean. Not all borosilicate glasses have this as a constant figure.*

specific gravity from 2.05 to 2.60 (*the low figures relate to the opal glasses which may not be actually a true crown glass type, but for convenience may be classed with them*). The barium crown glasses rise above these figures and have a range of R.I. of between 2.87 and 3.66. These are often classed in the second or flint glass group. This group, the flint glasses, contains silica, potash or soda and lead oxide which increases the brilliancy and dispersion. These glasses have a range of R.I. of between 1.51 and 1.80 and over, while the S.G. varies between 2.56 to over 6 (*refractometer dense glasses are flint glasses, dense lead glasses, having a refractive index up to 1.96*).

The specific gravity rises in conformity with the R.I. The figures given are the full ranges of the two types, but with imitation gemstones the ranges are much closer, viz.: Crown glasses = R.I. 1.52 to 1.54, S.G. 2.53 to 2.57, and for flint glasses = R.I. 1.58 to 1.68, S.G. 3.15 to 4.15.

As will be seen with the figures for the complete range,

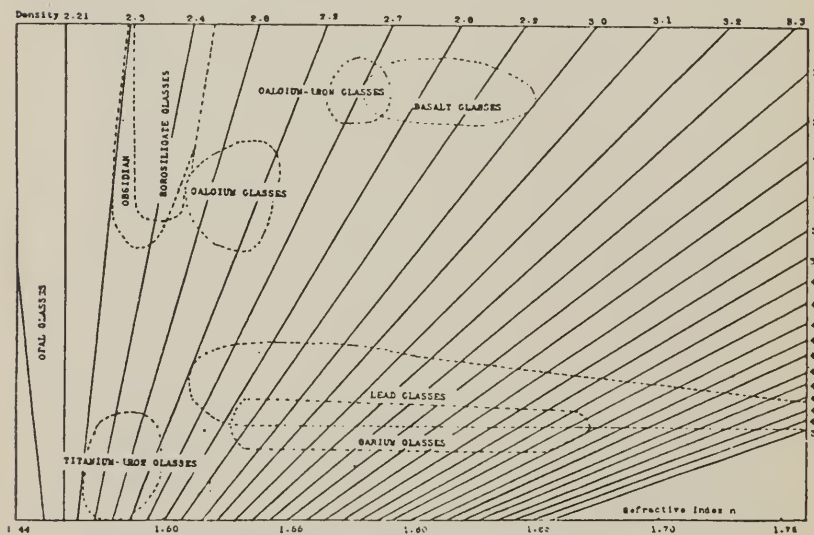


FIG. 42.—A chart for determining the composition of glass used in imitation gems. (After Bannister)

the constants overlap one another to a small extent. A better classification, depending on the composition, divides the glasses into definite groups. The table on p. 105 gives some indication of these glass families and their constants.

It may be of no great importance to the gemologist to be able to classify a glass into its special group, but it may give considerable contributory evidence in some general testing and have great value in certain special determinations

calling for extreme accuracy in identification. This sorting out into different groups may conveniently be done solely by recourse to refractive index and specific gravity determinations aided by a formula worked out by Mr. F. A. Bannister. This formula is based upon the relation of the constants of a glass to the constants of silica glass. The formula is as follows:—

R.I. of specimen—R.I. of silica glass (1.46)  
 S.G. of specimen—S.G. of silica glass (2.21) plotted  
 against the R.I. of specimen.

Each group was found to occupy definite areas on a graph. For convenience, Mr. Bannister devised a special graph in which the arithmetical computation is not necessary. This graph is illustrated in fig. 42.

The colour of a glass imitation gemstone is produced by the inclusion during manufacture of some chemical element or compound, which in the case of the lead glasses needs to be small in amount and does not materially alter the physical and optical constants. A short table showing some of the more important colouring compounds (or elements) under the colours they produce is now appended. Combinations of two colourings are possible and conditions of melt have considerable influence in determining the precise shade.

---

Violets and Mauves,		
Purples, etc.	...	Manganese or nickel, in potash glasses.
Blues	... ..	Cobalt.
Blue-green	... ..	Copper, or iron in the reducing condition.
Green	... ..	Sesquioxide of chromium, iron in the ferrous state.
Green-yellow	... ..	Chromium compounds; uranium compounds (fluorescent); iron in reducing condition.
Yellows	... ..	Silver salts; Titanium compounds; Cadmium sulphide; Sulphur, also combination of iron and manganese.

Brown-yellows	...	Sulphur with carbon; iron oxide; Uranium in quantity.
Browns	... ..	Iron; Nickel, when in soda glass.
Pinks	... ..	Selenium, under certain conditions.
Reds	... ..	Copper with controlled reducing conditions (brilliant ruby); Selenium compounds or the element itself (ruby glass with orange tint); Gold (ruby with a purplish tint which is sometimes corrected with the addition of silver); Iron oxides in the ferric state.
Smoke tints	... ..	Platinum or iridium.

---

Opaque stones such as turquoise require the use of opacifiers beside the use of colouring compounds. The strong apple-green fluorescence seen with many paste stones, generally yellow-green colours, and usually attributed to uranium, must not be taken as conclusive evidence that the glass does contain uranium, as manganese in certain states also produces this rather spectacular fluorescence when the stone is bathed in ultra-violet light (*this remark may also apply to the synthetic spinel of yellow-green colour*).

There is one characteristic of nearly all glasses, that is, the low degree of hardness of paste stones, less than six, except in the case of certain *case-hardened* types. All these ordinary pastes, therefore, yield to an ordinary file, a test given in every text-book, despite that as a test it should be decried. A student often feels at a loss when dealing with paste stones by the use of instruments, although pastes are singly refractive to light, and hence monochroic, some doubt may still be felt, especially with colourless stones and those with weak or no dichroism. Again the refractive index may appear, in white light, to have the index of that of a gemstone which the paste may simulate. To this end some remarks, and some figures, may be given which may help in an easier and more accurate distinction.

If it is possible to obtain determinations of both the refractive index and the specific gravity of a suspected paste stone,

<i>Colour.</i>	<i>R.I.</i>	<i>S.G.</i>	<i>Type of glass.</i>
Sherry-brown ...	1.48	2.42	Calcium, titanium and iron.
Bottle-green ...	1.495	2.31	Borosilicate.
Pale blue ...	1.50	2.36	Borosilicate.
Cobalt blue ...	1.51	2.47	Calcium glass.
Brownish-yellow	1.515	2.44	Calcium glass.
Uranium-green	1.515	2.48	Calcium glass.
Lemon yellow ...	1.53	2.56	Calcium glass.
Smoky colour ...	1.53	2.60	Calcium glass.
Sage green ...	1.57	2.67	Calcium iron glass.
Sea blue ...	1.585	2.63	Calcium iron glass.
Amethyst colour	1.57	3.38	Lead glass.
Red ...	1.58	3.18	Lead glass.
Pale blue ...	1.615	3.52	Lead glass.
Pale yellow ...	1.62	3.56	Lead glass.
Red ...	1.63	3.75	Lead glass.
Rose red ...	1.63	3.71	Lead glass.
Green ...	1.635	3.74	Lead glass.
Colourless ...	1.635	3.78	Lead glass.
Dark red ...	1.64	3.74	Lead glass.
Dark purple ...	1.64	3.76	Lead glass.
Colourless ...	1.64	3.75	Lead glass.
Pale blue ...	1.64	3.71	Lead glass.
Sapphire blue ...	1.645	3.80	Lead glass.
Peridot green ...	1.67	4.12	Lead glass.
Pink ...	1.08	4.07	Lead glass.
Pink ...	1.69	4.20	Lead glass.

little confusion can arise, for the combined values have in general no similarity to those of a real stone. With topaz and beryl, and natural gemstones with constants of similar value, this generalization may not strictly be true; for example, a

paste stone of pale blue colour having values of refractive index and specific gravity of 1.615 and 3.52 respectively could be a blue topaz with these figures (*it is inferred that the refractive index observations would, as in ordinary testing work, be made in white light; if monochromatic light, or a spinel refractometer were used, the double refraction would be apparent if the stone was a topaz*). Anyway specific gravity determinations are not easily performed in the general routine work of business and a discussion of other tests which may be more convenient are indicated. Before leaving the subject of the R.I. and S.G. of glass, it may be of interest to note that of a test parcel of ninety-five paste stones, all were found to have refractive indices lying between the range of 1.48 to 1.69, and colour did not appear to have any particular bearing on the R.I. value; however, it showed that it was rare to find a red paste with an R.I. below 1.62 and also that the reds, with the pinks and some peridot-greens, showed the highest figures, viz., 1.67 to 1.69. Likewise the table on p. 109 shows the combined values of a series of typical paste stones, and may do more to show what values one may expect to find in glass imitation gems, than pages of wordy discourse.

Glass, as in the case of the synthetic gems, shows under the microscope the unnatural nature of its formation due to the comparatively rapid cooling. While the synthetic gemstones show their origin by curved colour bands and by gas bubbles which are oriented along the curved layers, the striæ of glass is always at random, and sweeps in irregular curves in all directions in the material (*swirl striæ*). Likewise the gas bubbles have no special orientation; they are often arranged in groups, chains or "necklaces," Plate IV<sub>B</sub>, which, under low magnification, sometimes appear similar to certain inclusions seen in real stones. Fissures and cracks may also appear, and small star-like markings may be seen which are due to incipient devitrification of the glass. Most sapphire blue pastes show a red colour when they are viewed through the so-called emerald filter, due to the coloration by cobalt. Pale blue pastes which owe their colour to copper and iron show green under the



filter; these pastes imitate the blue aquamarine, blue zircon and the pale blue Ceylon sapphire. All green pastes show green and the amethyst colours show yellow to yellowish and brownish-red, similarly to the natural quartz amethyst.

## OTHER MATERIALS

Some opaque gems and ornamental stones may be imitated in porcelain, a medium which is particularly suitable for imitations of turquoise. Little information is given in the literature as to the density of this material; however, the

	<i>S.G.</i>	<i>R.I</i>
Cellulose nitrate ... .. (celluloid) ... ..	1.35 to 2.0 usually 1.37 to 1.43	1.495 to 1.520
Cellulose acetate ... .. (safety celluloid)	1.29 to 2.0 usually 1.29 to 1.35	1.49 to 1.51
Acrylate resins .. .. ("Plexiglass" and "Lucite")	1.18 to 1.19	1.495 to 1.500
Casein ... .. ("Lactoid," "Galalith," etc.)	1.315 to 1.39 usually 1.32 to 1.34	1.54 to 1.56
Phenol bakelites ... .. ("Bakelite," "Catalin," etc.)	1.2 to 1.7 clear types 1.25 to 1.35	1.56 to 1.67
Urea bakelites... .. ("Beetle," etc.) ... ..	1.48 to 1.55	1.55 to 1.62
Polystyrene ... .. ("Lustron," "Styron," etc.)	1.05	1.59 to 1.67

range of specific gravity may be said to lie between 2.1 to 2.5. The only other material which is used for gem simulation is the group of artificial resins popularly known as the "plastics." They have one thing in common, their extremely low specific gravity and hardness, which precludes any possibility of misidentification, except, perhaps in the case of amber and jet. Amber has a lower S.G. than any plastic in general use, while jet chips when a knife-blade is applied to it contrary to the artificial resins, which peel. For guidance a table of the constants of the different types of the plastics is given on p. 117

### **Recapitulation**

Most imitation gems are made of glass which has silica as a base.  
Two main types "Crown" and "Flint."

Coloured glasses are made by the inclusion of a trace of metallic oxides or other pigments.

Glass is isotropic (singly refracting), hence cannot show dichroism.

Glass generally shows characteristic structure of its unnatural origin.

Plastic imitations of gems are characterized by their lightness.

### **Test Questions**

52. What species of gemstones are made synthetically for the market?
53. Who first made rubies?
54. What is a reconstructed stone and are they now made?
55. A sky-blue stone is thought to be either an aquamarine or a synthetic spinel. What would be the quickest method to use to find out which it is?
56. What is the name given to the pear-shaped mass of synthetic corundum that is taken from the furnace?
57. Who made diamonds?

## CHAPTER XII

### ASSEMBLED STONES AND ARTIFICIALLY INDUCED COLOUR

GLASS imitations of gemstones are comparatively soft and can be easily scratched by an ordinary steel file. The file has long been used by many jewelers in tests to distinguish glass from the more important gem species, such as diamond 10, corundum 9, and beryl  $7\frac{3}{4}$  on Mohs' scale of hardness. In an effort to produce inexpensive stones which would both resist the file test and increase the wearing qualities, assembled or composite stones such as the doublet were devised.

The true doublet consists of two pieces of real stone cemented together so that the *crown* or top part consists of one piece of stone and the *pavilion* or base of another piece of stone, with the plane of cementing along the plane of the girdle (fig. 43). Thus, one can have a *diamond doublet* consisting of two parts of diamond, or one of two parts of sapphire, or of ruby, etc., the idea being to produce

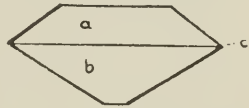


FIG. 43.—True doublet.  
a and b = real stone.  
c = cement joint

from two smaller pieces of material an apparent homogeneous stone, much larger and more important than could be obtained from either of the two individual pieces. These, however, are not common. If such a stone is immersed in oil and examined by a microscope, the tube being racked down so as to gradually focus through the thickness of the stone, the cement layer will show up owing to the bubbles it contains. If the stone, held in a good light, is viewed in different directions through the crown facets, the plane of joining will often show up as a reflecting surface, and if a doublet is

boiled in alcohol (or even in boiling water) the cement will dissolve and the two pieces will fall apart. It should be remembered that the refractive indices of both the top half and the bottom half of a true doublet will be those of the real stone, likewise the specific gravity will not be far from that of the real species, for the thin cementing layer will be too little materially to affect the determined result, hence neither of these constants will help in detecting such a fake. As it would be very unlikely that the two pieces of stone would be correctly oriented one to another, between crossed nicols such a doublet would not produce a field four times light and four times dark during a complete rotation of the stage; likewise one would expect the directions of dichroism to be also confused.

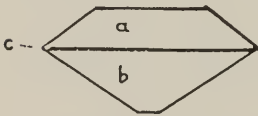


FIG. 44.—Souldé emerald.  
a and b = two pieces of colourless beryl (or quartz). c = green coloured cement join

Most of what has been told in the last paragraph holds good for the emerald composite counterfeit stone, which has a market to-day under the name *souldé emerald* (*souldé* = soldered. — Fr.). In America the stone is termed the

*soldered emerald*. There are two types of this composite stone: one made with a crown and pavilion of pale green or colourless beryl joined together by a cement to which has been added a proportion of green colouring matter in order to give the stone the desired colour; a second, and more usual type, consists of a crown and base of colourless quartz (rock crystal) (fig. 44). In order to enhance the simulation, the pieces of stone selected for the crown and pavilion are pieces which contain natural inclusions and feathers. The souldé emerald is easily detected, for if the stone is held by tongs in a white porcelain dish of water, and viewed sideways; the top and base appears nearly white and the cement joint shows up as a dark green line. Readings of refractive index for the first type give the R.I. of beryl, *i.e.*, 1.57–1.58, while that for the second type will be as for quartz = 1.54–1.55. Dichroism

is absent, for colourless quartz can show no dichroism and if the pale green beryl is used, the tint is so weak that the dichroic colours do not show. When viewed through the so-called emerald filter, soudé emeralds appear green and not reddish as in the true emerald.

The doublet most commonly met is that which has a base of suitably coloured glass and topped with a crown of almandine garnet. The coloured glass determines the colour of the stone while the garnet top, while doing its duty in giving a hardness to the face of the gem, does not in any way affect the colour (fig. 45). If such a stone—and these stones are made to resemble all colours in gems—is turned table facet downwards on a piece of white paper a red ring is seen around the girdle. This does not hold good when the stone is a red colour. If the refractive index is taken from the table facet the reading will be anywhere within the range for the pyrope almandine series, *yiz.*, 1.76 to 1.81; generally they are about 1.79, while the index, if taken from a back facet, can be any of the glass range.

Generally the index figure is about 1.62. Both the glass and the garnet are singly refracting, so that these doublets do not show dichroism. The green colour, which may be said to represent the emerald, shows green under the so-called emerald filter. These counterfeit stones are not made now; they are usually found in old jewellery. If these stones are viewed with a microscope using a low power objective, it will be commonly found that when the cement layer is focussed, not only are the characteristic bubbles in the cement seen but also the crystal inclusions in the slice of natural garnet. These often take the form of a cross-hatching of rutile needles. (Plate IVA).

These garnet-topped doublets are not produced by cutting two pieces, one of glass for the pavilion and one of garnet

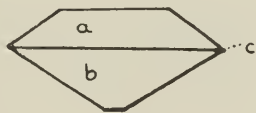


FIG. 45.—Garnet-topped doublet. a = crown of red garnet. b = pavilion of suitably coloured glass. c = cement or fused join

for the crown, and then cementing them together, but by a method whereby a piece of garnet is cemented or "fused"



FIG. 46.—Garnet-topped doublet with thin layer of red garnet fused across the table. a = garnet, b = glass

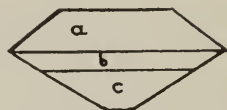


FIG. 47.—The triplet. a and c, real stone, b, coloured glass.

on to a rounded piece of glass of the desired colour. The stone is then cut complete. In this way it does not always

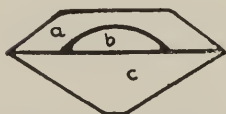


FIG. 48.—Liquid-filled triplet. a, real stone. b, coloured liquid in cavity. c, either glass or real stone.

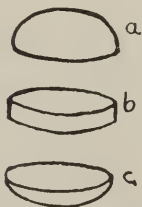


FIG. 49.—"Star quartz" doublet ("exploded" view). a, piece of star quartz. b, piece of blue glass with metallic mirror on lower face. c, base piece of blue chalcodony.

give the plane of joining along the plane of the girdle, therefore the crown may not in all cases be completely garnet. The line of joining may be halfway up the side facets of the crown, or even, the result may simply produce a layer of garnet across the table facet (fig. 46).

In order to overcome the risk of a jeweller testing with a hardness point (file) the pavilion facets, the *triplet* was devised, in which, as is shown in fig. 47, the crown and base is of real stone, with a centre as a piece of suitably coloured glass. These, however, are rare, as is another type, reported in an American text-book, in which the colour is produced by a liquid contained in a hollowed out cavity, as shown in fig. 48

The last composite stone to be discussed is one that is comparatively a recent achievement and is made to simulate the star corundum (*asterias*)

Fig. 49 is an "exploded" view of this stone; the top consists of a cabochon of star rose quartz on the base of which is cemented a suitably cut piece of blue glass having on its under-side a metallic film which acts as a mirror. Below this, to complete the stone and to protect the mirror film, is a piece of blue chalcedony. These stones are quite good imitations of star sapphires, but if held close under a strong light the star appears to alter in size when the stone is moved nearer to, or further from the light source. This effect, due possibly to the combination of mirror and cabochon (lens like) star quartz, is very striking and is not found in the true star corundum. More recently a modification of this counterfeit has been marketed, in which the rose star quartz is simply backed with blue cement. In this case detection is easy as the specific gravity of quartz is 2.65, while that of corundum is 3.99. It may be well to recall that these stones are sold, not as "star sapphires" as might well be expected, but as "star quartz," starolite, etc.

One of the more interesting points in the study of gems is the facility with which certain gemstones are able permanently to change their colour when influenced by heat and other radiations, and when crypto-crystalline materials (such as the chalcedonies) are stained or dyed with different colouring matter.

Diamond, one of the purest substances, occasionally assumes other tints. These tints are rare, except the browns and yellows, the so-called "off-colour" stones; it is remarkable that, despite the attention that has been paid to the King of Gems, little information is available as to the cause of these shades of colour. The lack of this knowledge, therefore, precludes, as it does with many different species which exhibit colour change from the effects of wave radiation, the understanding of the change to green colour of many diamonds, particularly the yellow stones, when they are left exposed to radium emanations.

Scientific investigation has shown that radium gives off radiations of three different kinds, termed respectively  $\alpha$ -,  $\beta$ -,



and  $\gamma$ -rays. The  $\alpha$ -rays are a stream of positively charged minute particles travelling with great velocity. It has been proved by many experimenters that an  $\alpha$ -particle is an atom of helium containing two positive electric charges. The  $\beta$ -rays are negatively charged particles, and have been found to be identical with the particles which make up the cathode rays (*the electrons, or electron stream, of vacuum or X-ray tubes*). The  $\gamma$ -rays are similar to X-rays, and are electro-magnetic vibrations, but are of much shorter wave-length than the X-rays. Recent research has shown that it is the  $\alpha$ -particle bombardment which gives rise to the colour change in diamonds. This colour change is permanent under ordinary conditions but may be destroyed by heating for some hours at about  $450^{\circ}$  C. and also by the heating set up in the process of repolishing. These radium-treated diamonds, like many other substances so irradiated, themselves become radioactive and are thus able to affect a photographic plate, a fluorescent screen or an electroscope. It is by applying the test for radioactivity that these radium-green diamonds may be differentiated from those rarely found natural green diamonds. Radium emanations tend to deepen the colour in many corundums and even in the colourless stones to induce it (in the collection of gemstones in the *Museum of Practical Geology* at South Kensington there is a white sapphire which has been turned brownish by the influence of radium. The colour has, however, tended to fade during the passing of the years). Citrines and amethysts which have had their colour driven off by the application of heat (to be mentioned later in the text) are reported to have the colour restored when subsequently treated by radium emanations. This restored colour may not be the tint the stone had before the heat treatment.

Many different species of gemstones are altered in colour when they undergo heating. These colour changes are in general permanent and have a great commercial significance. The application of heat to coloured corundum and quartz has the effect of weakening the colour. Purple sapphires are heat-treated to produce a rose red or pink colour, while amethyst,

which turns colourless under great heat, with a moderate temperature may turn to a deep orange, the so-called "Spanish topaz." Brown tourmaline loses its colour by heat, producing the colourless variety—achroite. The tourmalines from Klein Spitzkopje in South-West Africa, of a dark blue-green colour, lighten, when heated to about  $650^{\circ}$  C., to a light green colour tinged with blue, which at times resembles the emerald. Some greenish beryl, when heated, changes its colour to a beautiful blue.

Probably the classic instances of thermal colour change are those of topaz and zircon, both species of which have an exceptional interest in modern gem trade. Brownish and yellow topaz from Brazil, when heated to  $500^{\circ}$  to  $600^{\circ}$  C., lose their colour, but on slowly cooling assume an attractive shade of pink which permanently remains. Should the heat be too great, the stone remains colourless and at too low a temperature the colour assumed is a salmon pink. The process is termed *pinking*, and the stones are known as "pinked," "fired," or "burnt" topaz. The brown zircons from Indo-China supply the material for the beautiful zircons now so popular and whose colour has been obtained by heat treatment. These brown zircons when heated in a reducing atmosphere, such as in a crucible packed with wood charcoal, which gives an atmosphere of carbon monoxide, usually turn a shade of blue. Stones of this hue are known under the name of Starlight or Starlite; the colour, however, is often fugitive. If the brown stones are heated in an oxidising atmosphere (in air) the colour assumed is golden yellow or colourless. The colourless stones are highly refractive and dispersive, and give a good simulation of diamond when they are viewed in a half light. These colourless stones are sometimes known as Matura diamond.

Materials of a crypto-crystalline nature, and thereby somewhat porous, are capable of being stained or dyed to various colours. This is particularly so in the case of chalcedony and agates. The so-called "black onyx" is produced by boiling chalcedony in a solution of sugar and water followed by

treatment with sulphuric acid. The action is as follows: During the first boiling the sugar penetrates into the interstices of the chalcedony and is deposited. Sugar has the chemical formula of  $C_{12}H_{22}O_{11}$ .  $H_{22}O_{11}$  is eleven times  $H_2O$  (or water) and in the final treatment, with sulphuric acid, the acid, with its great affinity for water, abstracts the  $H_{22}O_{11}$ , leaving  $C_{12}$ , which is carbon, and in the form of soot, in the interstices and thus producing the black colour. Ferrous sulphate solution gives a blue colour to a chalcedony which has previously been soaked in potassium ferrocyanide, while if the stone is soaked in ferrous sulphate and then heated ferric oxide is left in the interstices which produces a red colour. Treatment with chromium and nickel gives green colours and with hydrochloric acid a yellow colour is produced. Various other shades are produced by the use of aniline dyes, but the colours are apt to be fugitive. Jasper, the impure quartz, is stained to produce *Swiss or German Lapis* and *Swiss jade*. Alabaster and amber are two other materials to which the art of staining has been actively applied. Bad coloured turquoise has had the colour enhanced by staining, and some opal has been so treated. Rock crystal has been heated till cracks are apparent and then placed in coloured solutions or inks, which enter the cracks and give the stone a coloured appearance. Another type of staining, if it can be so called, is used for the purposes of deceit. "Off"-coloured diamonds are painted on the back facets with aniline blue, which appears to correct to some degree the yellowish colour and make the stone whiter in appearance and more valuable. The effect lasts only for a short time. Washing in spirit will usually remove the colour and unmask the fake, though recently some faked stones needed boiling in acid for removal of the colour. If the facet edges and the ground edge of the girdle are examined with a lens some of the blue colour will show up. Poor coloured emeralds are often found with the back facets painted green and the Mexican water opal is sometimes found with the back painted black. The latter artificial coloration, one is told, is not fraudulent.

### **Recapitulation**

A doublet is made up of two pieces of stone, or one piece of stone and one of glass.

A triplet consists of three pieces.

The soudé emerald is the most important composite stone. It may be made either with a colourless quartz body or with one of colourless or greenish beryl.

There are three methods whereby colour may be artificially induced in certain gemstones: Radium emanations, heat and by staining.

Diamonds, corundums and certain varieties of quartz are altered in colour by the emanations of radium (diamonds turn green).

This has little commercial importance.

Topaz (brown), certain varieties of quartz, tourmaline, zircon, corundum and beryl change colour on being subjected to heat.

Crypto-crystalline material is the type most amenable to staining. Chalcedony the most common material so treated. This gives such stones as "black onyx," "stained chalcedony" (chrysoprase), "Swiss lapis," etc.

Painting the back facets of stone is not permanent and is in general only done for a fraudulent purpose.

### **Test Questions**

58. Two monochroic red stones are both found to have a specific gravity of 4.10, but one has an R.I. of 1.805 and the other 1.665. Can you identify these stones?

59. In the synthetic emerald "igmerald" two constants are sensibly lower than found in the natural emerald. Which are these two constants?

60. Does the emerald filter give help in the detection of all blue paste stones?

61. White topaz and colourless glass have similar constants of refractive index and specific gravity. How would you differentiate between the two? Give two methods.

62. What superiority does the synthetic gem possess over the glass imitation gem?

63. What is the important characteristic of "plastic" imitation gem?

## CHAPTER XIII

### STYLES OF CUTTING

It has already been learned that when gemstones are found in nature they may have distinctive forms with plane and often lustrous faces. These faces and edges may suffer attrition during the course of the countless years since their original formation, and may be completely rubbed away, leaving a simple rolled pebble. Even in the most perfect crystal there is little likelihood of the gem showing the beauty and symmetry which is brought out by the art of the precious stone cutter or lapidary, as he is more correctly called, although it may be pointed out that the man who cuts diamonds prefers not to be so named, but is simply known as the diamond cutter, the lapidary being a worker whose job is principally the cutting of fine gems from the species which supply precious, "semi-precious," rare and ornamental stones.

There is one main difference between the fashioning of diamonds and that of other stones. Diamonds can only be cut and polished by their own powder, and the cutting and polishing is carried out on a rotating lap in one operation. In fact, the polishing of diamond is simply a fine grinding, that is the "hills and dales" are gradually rubbed down level. It is remarkable that with the other gemstones the final process of polishing is not a fine grinding but a flowing of the surface layer of atoms which produces an amorphous layer, the Beilby layer, which either remains amorphous or re-crystallizes.

In the cutting and polishing of other stones, two separate processes are carried out, again on rotating laps. The facets are cut by the use of hard abrasives to obtain the outline and shape of the finished stone. This leaves the faces with a ground-glass effect. Each of these facets is now polished on

another lap using various soft polishing materials, such as rotten-stone, tripoli powder, etc., in order to produce the mirror-like surfaces seen on a cut stone.

So that the maximum beauty of a stone may be apparent, certain definite shapes and angular measurements, particularly in the case of diamond, are necessary. In dichroic stones, such as ruby, sapphire, emerald, tourmaline, etc., care has to be taken that the table facet is placed in the correct direction to ensure the best colour. All this has of necessity produced a series of "styles" of cutting most suitable for each particular type of stone. These styles will now be briefly described.

#### CABOCHON CUTS

The simplest cut for a stone. Consists of a curved (or domed) upper surface, which may be low, medium or steep, with a base of less curvature (double cabochon), or flat, or the base may be hollowed out. The outline of cabochon cuts may be circular, oval or elliptical, or even pear-shaped. This style is most suitable for translucent and opaque stones such as turquoise, star stones, opals, lapis and almandine garnet. To this last named stone the hollowed base cabochon is the style most usually applied.

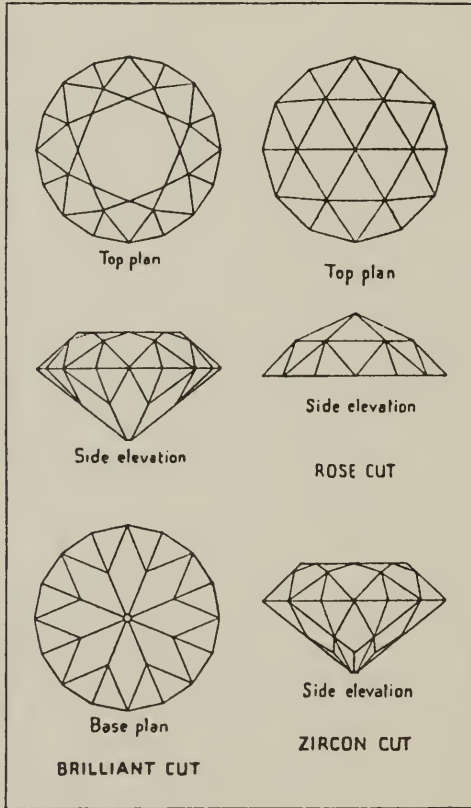
#### ROSE CUT

Generally used for cleavage fragments of diamond, and for the pyrope garnet used in Victorian jewellery. The rose cut consists of a series of triangular facets of equal size rising from the flat base and terminating in a point at the apex. A double rose may be explained as being two roses base to base.

#### BRILLIANT CUT

This is the perfection cut for diamond; the cut which allows the greatest amount of brilliancy and "fire" to be seen. There are fifty-eight facets in the standard brilliant cut, thirty-three above the girdle and twenty-five below. In an ideally proportioned diamond brilliant the angle between the crown facets and the girdle should be  $30^{\circ} 31'$ , and simi-

larly that between the girdle and pavilions should be  $40^{\circ} 45'$ . Hence depth of the crown should be slightly more than one-quarter of the total depth of the stone.

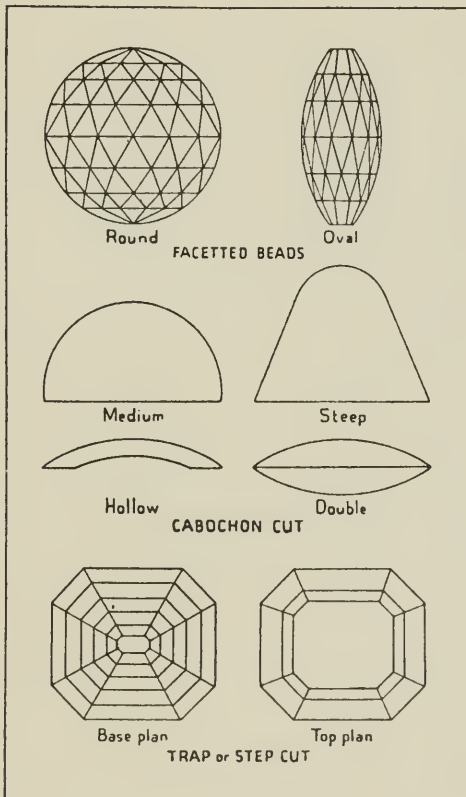


The outline is most usually circular, but may be cushion shaped or even square. If the outline is pear-shaped, the stone is called a "pendeloque" brilliant, and if oval with pointed ends, is termed "marquise" shaped.



ZIRCON CUT

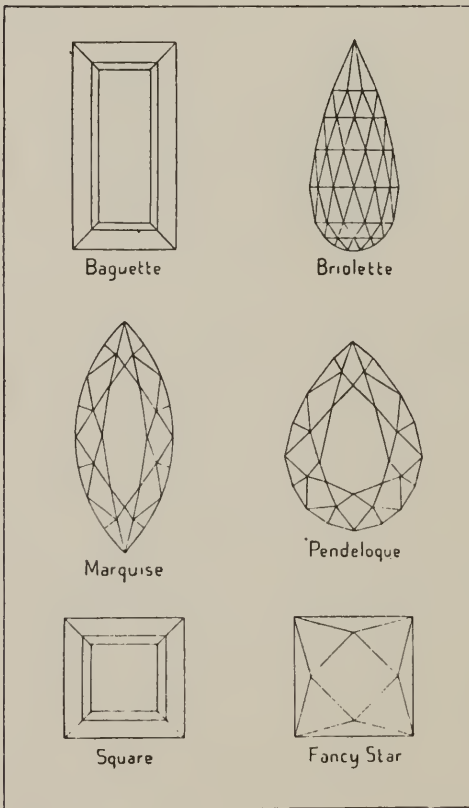
This cut is similar to the brilliant cut with the addition of a set of facets on the pavilion reaching half way up from the



culet (the small facet at the bottom of the stone and parallel to the table facet) to the girdle. This is a style very evident in the zircon.

## STEP, TRAP OR EMERALD CUT

This cut, which may be arranged on an outline of a square with cut corners, square, oblong, triangular, long bag-shaped



(baguette) and various fancy outlines, has a table facet and a series of rectangular facets arranged parallel to the girdle both on the crown and base. This cut is desirable for emeralds

and other colored gemstones when revelation of actual body color is especially desired. In modern practice many fine diamonds have been cut in this fashion producing brilliant and beautiful gems which, however, possess less fire than brilliant-cut diamonds.

#### MIXED CUT

This cut, which is used for various coloured stones, consists of a crown cut in the brilliant style and with the base step cut.

A *briolette* is a drop-shaped stone having its entire surface cut with triangular facets. *Seal cut* is the name applied to a stone, usually trap cut, with a wide table. A *cameo* is a stone with a raised carved image; if the carving is engraved into the stone, as for the purposes of a seal, the stone is termed an *intaglio*. A *curvette* is a cameo engraved so that the design has a hollowed background with the edge of the stone raised as much as the central design.

#### **Recapitulation of**

Two main styles of fashioning: with curved faces and with facets.

Curved faced fashioning (cabochon cuts) are used for translucent stones and where special effects are required to be brought out.

Cuts with plane facets must have definite proportions in order to bring out the full beauty of the gem.

Certain styles are best for certain species, e.g., "brilliant" for diamond, "step" for emerald.

#### **Test Questions**

64. For what reason was the garnet topped doublet devised?
65. What is "Swiss Lapis"?
66. Name three stones which permanently change their colour after being heated.
67. What crypto-crystalline stone is most usually treated by staining?
68. What stones are liable to change their colour when they have been treated for some time to the emanations from radium or radium bromide?
69. What is the name applied to the composite stone which makes such an effective counterfeit for the emerald?
70. How would you test a colourless stone for the existence of double refraction?

## CHAPTER XIV

### THE PEARL

THE earlier chapters of this book gave account of gems and imitations which were the products of the mineral constituents of the earth, or, in the case of the counterfeits, the fruits of the work of the world's chemists and technologists. However, there is one group of gems which have as their genesis the living creature or the growing plant, that is, their origin is organic and not mineral.

Chief among this group of gems is that prized possession, the pearl, that gem of Queens which from remote days has always been known as "The Queen of Gems." Embellished with legend and fact, pearl, despite its lack of durability, has survived all endeavours to relegate its importance below that of its consort—diamond.

What is pearl, and how is it formed? These are the first and essential questions to consider, for beyond the common knowledge that pearls are found in oysters, little other information is imparted to the ordinary layman. Practically all shellfish, and in particular all those which are grouped in the zoological phylum mollusca, have the power to produce the substances which together produce pearls and mother-of-pearl, but it is only in certain types that pearls as we know them as gems are found.

The "oyster" (for the animal is not strictly an oyster, at least not of the same zoological family as are the succulent morsels so well known to the gourmet) has the power to secrete crystalline carbonate of lime and an organic substance known under the name of conchiolin in order to produce the hard covering, or shell, which serves as the protection to the soft body of the animal, and it is this secretion which will, in certain abnormal conditions, where damage or injury causes

irritation to the animal, produce the various types of pearls. There are two main types of pearls; the *cyst* pearls, which are spherical or pear-shaped pearls found inside the body of the animal and constituting the finest and most valuable type of gem; and *blister* pearls, which are those found attached to the inside of the shell, and are produced by a piece of irritant lying between the inside surface of the shell and the outside of the animal, which has been covered over by the pearly secretion. Other names sometimes applied to pearls are as follows: *Button* or *Bouton* pearls are cyst pearls which have rounded tops and flat bases, while *drops* or *pear-eyes* are, as their name implies, pear-shaped, and are always cyst pearls. *Baroque* or *Barrok* pearls are irregularly shaped pearls which may be either cyst or blister in formation. *Seed-pearls* is the name applied to very small pearls. *Fresh-water pearls* or *mussel-pearls* are pearls found in mussels of the family *Unionidæ*, which live in inland waters and rivers. A full list of the various types of pearl oyster and mussel and other shellfish which produce pearls will be tabled later.

Before proceeding further, it may be as well to give some indication of the general structure of the pearl-forming mollusc. One of the more rudimentary forms of animal life, the mollusc consists of a soft visceral mass, having no head, but obtaining its sustenance through gills. The rest of the animal consists of a *foot* and a bundle of horny threads, termed the *byssus*, whereby the animal attaches itself to the rocky sea bottom. Lastly, but of utmost importance in the production of pearl and mother-of-pearl, is the *mantle*, a double flap which completely encloses the animal, and consists, at least on its outer surface, of epithelial cells which are capable of secreting the various constituents which go to the making of pearl and mother-of-pearl. The mantle has the property of being able to secrete the various components in a given order; thus, in the secretion of the material for the shell, the cells at the outer edge of the flaps secrete a brownish, organic substance which approximates to the formula  $C_{30}H_{48}N_2O_{11}$  and which is termed *conchiolin*. Nearer the centre

of the mantle, the cells secrete carbonate of lime (calcium carbonate =  $\text{CaCO}_3$ ) in a form of prismatic crystals minute in size, while the secretion from the cells at the centre of the mantle is also carbonate of lime, the crystals are in the form of flakes, and arrange themselves in an overlapping arrangement reminiscent of roofing tiles. This layer produces the beautiful iridescent *nacreous* surface so well known in mother-of-pearl. Hence, by this process, the shell of the animal is built up of an external layer of brown conchiolin (the *periostracum*), a layer of variable thickness of carbonate of lime in the prismatic form, and, finally, an inside layer of the platy form of carbonate of lime. This smooth layer, known as the



FIG. 50.—Diagrammatic picture of the layers in a pearl "oyster" shell. A, platy nacreous layer. B, prismatic layers. C, conchiolin layer (the periostracum).

*nacreous layer*, forms, therefore, a smooth surface for the body of the animal to rest upon. One point which should be made clear concerning the nacreous layer, or layers, of the shell is the fact that the small crystals are deposited so that the long axis (the vertical crystal axis) of the crystals are vertical to the plane of the layers, see fig. 50. It is important to understand this, as upon it depends the various testing methods.

The beautiful iridescent lustre of mother-of-pearl and pearls is due to a combination of two optical phenomena, and the combined effect is termed the *orient*. It is due to the combined effect of interference of light at thin films (as in the case of opal), and diffraction of light from the fine lines, or edges, produced by the overlapping of the flakes of the nacreous layer.

So much for the shell and mother-of-pearl, a natural arrangement to protect the animal. What, then, of pearls in

the scheme of things? It should be noted when a shell is examined that the outside is rough while the inside is smooth, smooth, as before pointed out, to rest against the outer envelope of the animal, however, should a sharp piece of grit, such as a grain of sand, a piece of broken shell, or even the intrusion of a shell-boring animal get between the shell and the mantle, it is logical to suppose that the animal would attempt to ease the irritation caused. This is precisely what

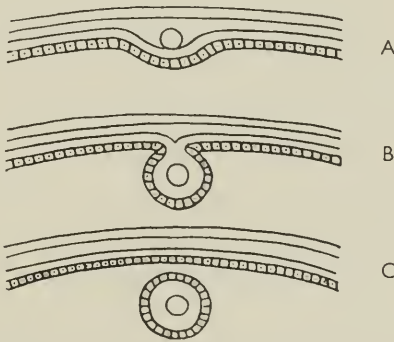


FIG. 51.—Diagrammatic picture of the formation of a "cyst" pearl. A, the irritant forms a dent in the "mantle." B, the "mantle" forms a pouch which contains the irritant. C, the pouch separates from the "mantle" forming a "cyst" in the body of the animal. This pouch is the "pearl sac" and contains the irritant.

it does, and it does so by secreting nacre over the obstruction, which is cemented to the shell and finished off by layers of smooth nacre. The bump, or bulge, produced on the shell may be removed and used as a jewel, and is then known as a blister pearl. This pearl is caused through an injury or protection against injury to the animal; in fact, all pearls are due to injury or disease, hence are an abnormal condition.

In certain conditions, the obstruction, or irritant, is not cemented to the shell, and a second method is adopted by the animal to immobilize the irritation. This method involves the formation of a pearl inside the body of the animal, and pro-



duces the so-called *cyst* pearl. The irritant, be it a grain of sand, a piece of shell or a minute parasite, gradually, and in successive stages, forms a dent in the mantle, fig. 51*a*; a bag-shaped pouch, fig. 51*b*, which eventually joins together at the neck, producing a hollow sphere, lined with epithelial cells quite separate from the mantle of which it was originally a part, fig. 51*c*. This sphere of cells is termed the *pearl sac*. The wound in the mantle coalesces and leaves the pearl sac within the animal as a tumour or cyst. The cells lining the wall of the cyst are still living, and go on secreting nacre over the irritant, thus building up the pearl. Given good position within the animal, the pearl is normally round in shape, but if in an unfavourable position may produce bizarre shapes (baroque pearls) or drops or boutons.

The percentage chemical composition of pearl is about 86 per cent carbonate of lime, 12 per cent of conchiolin and 2 per cent water, and the structure is made up of concentric shells (the so-called onion structure) with minute crystals of carbonate of lime arranged normal to the concentric layers so that the structure can best be expressed as being concentric and radial. This is a point which is essential to remember, as upon this structure depends the methods of testing. The density of pearl lies within the range 2.60 to 2.78; however, each fishery usually conforms to a narrower range of density. These closer figures are in the table given later. The hardness of pearl is about three-and-a-half to four.

The chief pearl fisheries are as follows: In the Persian Gulf, off the coast of Arabia; the Gulf of Manaar, off the north-west coast of Ceylon; off the north-west coast of Australia; the Mergui Archipelago, off the coast of southern Burma; the Sulu Sea; around New Guinea and Borneo; certain Pacific islands, including Tahiti; the Gulf of Mexico and off the coast of Venezuela and the Gulf of California in the New World. Fresh-water pearls are found in rivers of England, Scotland and Wales, and in the rivers of North America.

Black pearls are obtained from the Gulf of Mexico and, to a limited extent, from certain Pacific islands; the colour is

thought to be caused by the nature of the water. Blue pearls are due to a large kernel of conchiolin, and are lead-grey in colour rather than blue. Yellow pearls are obtained from Sharks Bay, Western Australia. Pink pearls are obtained from a univalve mollusc, the great conch, fished off the coast of Florida and the West Indies. These pink pearls are characterized by the lack of nacreous coating and by their high specific gravity = 2.85.

Other molluscs which sometimes produce pearls are the giant clam (*Tridacna gigas*), the wing-shell (*Pinna*), the sea mussels (*Mytilidæ*), and the following mussels, the niggerhead (*Quadrula ebena*), the bullhead (*Pleurobema*), the butterfly (*Plagiola securis*), the buckhorn (*Tritigonia verrucosa*) and some others. An oval section of the rounded whorl of the nautilus, backed with cement, resembles a blister pearl, and is called *coque de perle*.

Owing to the organic constituent, pearls, unlike the gems cut from crystals, are not so durable, being much softer. Moreover, each crystallite of carbonate of lime is kept in its place by a cementing of the organic conchiolin, and this constituent may deteriorate during the course of years, turn dark, show cracks, and subsequently crumble away.

#### CULTIVATION OF PEARL

It has been explained that if a foreign body gets between the shell and the body of an oyster or mussel the animal takes steps to cover the intruder with nacre, and thus produces a blister pearl. Knowing little of the science of the pearl-bearing molluscs, the Chinese, in the thirteenth century, found that if they inserted an object between the shell and the animal, it subsequently became coated with pearly nacre. Even to this day, metal figures of Buddha are so treated. During the later half of the nineteenth century, the Japanese advanced on the method. They cemented mother-of-

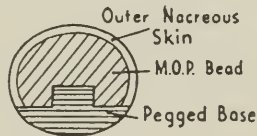


FIG. 52.—Half-cultured pearl.

TABLE

*Pearl Composition.* Carbonate of Lime (aragonite) S.G. = 2.94  
 Conchiolin. S.G. = 1.34  
 Water. S.G. = 1.00

<i>Locality.</i>	<i>Mollusc.</i>	<i>Colour of Pearl.</i>	<i>Range of S.G.</i>
Persian Gulf ...	<i>Margaritifera Vulgaris.</i>	Creamy-white	2.68 to 2.74
Gulf of Manaar.	<i>Margaritifera Vulgaris.</i>	Pale cream-white.	2.68 to 2.74
North coast of Australia.	<i>Margaritifera Margaritifera.</i>	Silver-white.	2.68 to 2.78
North-west coast of Australia.	<i>Margaritifera maxima.</i>	Silver-white.	2.67 to 2.78
Sharks Bay, W. Australia.	<i>Margaritifera carcharium.</i>	Yellow.	
Venezuela.	<i>Margaritifera radiata.</i>	White.	2.65 to 2.75
Japan (natural).	<i>Margaritifera martensi.</i>	White, with greenish tinge.	2.66 to 2.76
Bahamas, and Florida.	<i>Strombus gigas</i> (the great conch).	Pink.	2.85
West coasts of Mexico and California.	<i>Haliotida</i> (the abalone).	Greens, yellows, blues, etc.	
Gulf of Mexico.		Black.	2.61 to 2.69
<i>Freshwater pearls.</i> North America.	<i>Unio.</i>	White.	2.66 to over 2.78
Europe ...	<i>Unio margaritifera.</i>	White.	
<i>Cultured pearls.</i> Japan ...	<i>Margaritifera martensi.</i>	White.	2.72 to 1.78

pearl pellets to the inner side of the shell of the mollusc. After the animal had been returned to the sea for some years and then again fished up, it was found that the pellet had been covered over the exposed surface with nacre. The bead was then broken away from the shell and the broken surface ground flat. A piece of mother-of-pearl was then pegged on to the ground base and finished by grinding to a symmetrical shape to produce the whole sphere (fig. 52). If these *half-cultured pearls* are mounted in a setting with a closed back, the raw mother-of-pearl base is not seen, but if they are unset, the deceptive nature is at once apparent.

It was not until 1921, after some seven or more years experimental work by the Japanese scientists led by Mikimoto, that the cultured pearl as we know it to-day, the *whole-cultured pearl*, appeared. The method employed to produce these pearls, highly technical in nature, has of late years been brought to a mass production basis. Briefly, the process is as follows: An oyster fished at maturity, that is about three years old, has inserted into its body, through an incision made with a scalpel, due care being taken that the wound is aseptic, a mother-of-pearl bead contained in a sac of epithelial cells formed from the centre of the mantle cut from another mature oyster, which is killed by the operation. This sac, containing the mother-of-pearl, is closed by a ligature, and the wound in the second, and living, oyster is antiseptically treated. The oyster is then returned to the sea for a period of years, being kept in wire cages during the time. On being fished up after this period of time, the bead is found to have been coated with a nacreous layer, the bag of epithelial cells having carried out the work of secreting the nacre in exactly the same way as that carried out by the pearl sac in the case of an oyster producing a natural pearl.

Let us now consider the difference between this cultured pearl, which from external examination appears much the same as the real pearl, and the pearl produced by an accident of nature. The natural pearl, when sliced through, appears to be a series of concentric shells with, or without, a distinguishable

nucleus. On the other hand, a section of a cultured pearl shows the parallel banded structure of the mother-of-pearl bead surrounded by a thin series of layers concentrically arranged around the bead.

At first placed upon the market as pearls from a new fishery, their true nature was not at once discovered; not until a pearl was broken and the mother-of-pearl bead discovered, was the character of this counterfeit made known. Then came the necessity of finding a method whereby these pearls could be distinguished from the natural pearl. It is obvious that one could not break open every pearl to find out whether it had a core or not. Probably the first attempt to find a solution was to use the valuable penetrating power of X-radiations to see if the core would show up as a darker shadow, as the bones of a hand show as a dark shadow through the much more easily penetrated flesh. Owing to the similarity of the composition of the mother-of-pearl bead and the nacreous layer, little convincing evidence showed, and in very few pearls was it at all possible to determine their origin. Cultured pearls, when viewed in the dark whilst they were irradiated by a beam of invisible ultra-violet light, were found to fluoresce with a greenish tint as against the sky-blue fluorescence of natural pearls. Unfortunately, again a snag destroyed the value of this test when it was found that later samples of cultured pearls gave a similar fluorescence to natural pearls.

Nearly all pearls are drilled through in order that they may be strung as necklets, and this string canal provides a means whereby the centre of the pearl may be examined. A special form of microscope will give much indication as to whether there is a bead centre present, but this method, much used by the German gemologists, does not provide conclusive evidence in all cases. Probably the most satisfactory means of detecting cultured pearls which have been drilled is by the *endoscope*, a French invention. The apparatus consists of a strong source of light which is directed down a narrow platinum tube fitted with two mirrors at angles of  $45^{\circ}$  in

opposite senses at its end. The pearl is threaded along the needle until the mirrors are central when the light passing upwards from the first mirror is, if the pearl be natural, reflected along the adjacent concentric layer to be reflected from the second mirror and out along the string canal. This is viewed by a low-power microscope and when the pearl is moved along the needle a flash is seen in the microscope eyepiece when the pearl is central on the needle (fig. 53*a*). Should the pearl be cultured, the reflected beam will proceed up and along the parallel layers of the mother-of-pearl bead, and will be seen as a streaky effect on the outside of the pearl. No flash of light is seen in the microscope eyepiece when a cultured pearl is moved along the needle (fig. 53*b*). This instrument requires some practice in operation, but in the hands of an experienced worker, something like 200 pearls an hour can be tested.

Should the pearl not be drilled, the endoscopic method is not available, and another method must be utilized. Earlier in the article it was mentioned that the use of X-radiations was not at first found practicable if used in the same way as in medical diagnosis, *i.e.*, shadow or so-called skiagrams, more recent research by Dr. A. E. Alexander has shown that more successful results can be obtained. There is still another way in which the radiations can be of use. Fluorescence generated by X-rays has some value, and earlier had been used with partial success. The method in use at the present day depends on the experimental work of scientists investigating the nature of X-rays. In 1912, Max von Laue instigated practical experiments based on the theory that X-rays were electro-magnetic radiations with a much shorter

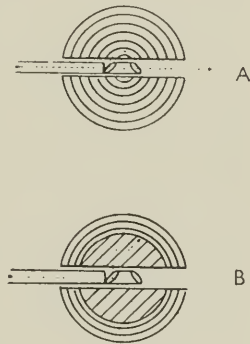


FIG. 53.—Sectional view of endoscope needle in natural and cultured pearl showing path of the light beam.



wave-length than light, and that if a structure could be found in which regular divisions were close enough together, then if the rays were as suggested, they could be diffracted by such a structure, as are light waves by a finely ruled glass diffraction grating. Using a crystal of copper sulphate, he found that this acted towards X-rays as a three-dimensional grating, thus proving the theory of the connection between the light rays and X-rays. Max von Laue also discovered that the pattern of reflected spots gave information of the atomic arrangement, thus leading to the science of X-ray crystal analysis.

It has been found that if a lauegram, that is the photograph of the spots diffracted from the crystal, is taken across the short axes of a bundle of aragonite crystals, the pattern shows four heavy spots, while if taken in the direction of the long axes, the design is hexagonal, with six spots. Now if a narrow beam of X-rays is passed through the centre of a real pearl, it is obvious that, owing to the radial nature of the small crystals, the beam must pass along the long axes of the crystals, and, hence, that a pattern will show the six-spot hexagon. If, however, a cultured pearl is so examined, there is only one direction in which the beam will pass along the long axes, thus producing a six-spot figure; all other directions will cut across the short axes of the crystals and, hence, show four-spot figures. In testing a pearl, should the first picture show a six-spot figure, the pearl must be rotated through a right angle, and a further photo taken. If this also shows a six-spot photo, the pearl is natural; if a four-spot figure is shown, the pearl is cultured. In general, one obtains the four-spot diagram at once with a cultured pearl, and no further testing is needed.

Recent careful determinations of the specific gravity of natural and cultured pearls, by B. W. Anderson and C. J. Payne, have shown that the cultured pearl has a relatively high specific gravity coupled to a more restricted range than the natural pearls. These workers found that if a suitable heavy liquid, bromoform diluted with toluol, or acetylene



tetrabromide, diluted with toluol, be made up to a density of 2.74, most cultured pearls will sink in the liquid, while most natural pearls will float. This provides a quick approximate test.

Cultured pearls show to the experienced eye blemishes which are characteristic. Practical experience is the only way in which an observer can learn to recognize the blemishes.

#### IMITATION PEARLS

The beginning of the imitation pearl industry, which markets imitation pearl necklets from sixpence to pounds, is coupled with the name of Jaquin, of Paris. There are two types of these glass bead pearls; one consists of hollow opalescent glass beads sprayed on the inside with *essence d'orient*, which is a composition made with scales from a small Mediterranean fish called the *bleak* and parchment size. The bead is then filled with wax to make it solid. The other type consists of a solid glass (or sometimes mother-of-pearl) bead upon which are placed several coats of *essence d'orient* which, after each coat has been applied, is burnished down. Some twenty coats may be applied in the better class of this type of pearl. Both these types may be detected by their smooth feel when rubbed over the teeth (a real or cultured pearl feels gritty) or by examination of the string hole which shows the glass edges and wear of the essence from the edge. In the first type, if a spot of ink is placed on the outside, the spot will show doubling due to the reflection from the underside of the glass sphere.

Black pearls have been imitated by polished spheres of hæmatite. These are easily detected by their greatly superior density (about 5.2). Pink pearl has been imitated in pink coral, but may be detected by the surface striations of pink coral, or by the higher density of pink pearl (2.85) to coral (2.7). Any plastic imitations of pink pearl (pink pearl, which lacks iridescence, being the only one that can be imitated in the synthetic resins) may be easily identified by the extremely low density of the plastics.

**Recapitulation**

Pearl consists of calcium carbonate, organic matter (conchiolin) and some water.

Pearl "oyster" and pearl mussel are the producers of gem pearls. A pearl may be defined as a radial and concentric arrangement of crystallites of carbonate of lime arranged around a central nucleus. The pearl-sac is essential for a round or pear-shaped pearl, but not for a blister pearl.

Orient of pearl is caused by the combined phenomena of interference of light at thin films and diffraction of light from fine lines or edges.

All pearls have a nacreous layer except pink pearls (Conch pearls).

A cultured pearl is a naturally formed skin of real pearl over a bead of base material (mother of pearl) which has been artificially introduced into the pearl-forming mollusc.

Two types, the half-cultured and the whole-cultured pearl.

Endoscopic method of pearl-testing depends upon the concentric arrangement of real pearl. The X-ray method depends upon the radial arrangement of the real pearl.

Cultured pearls have a slightly higher specific gravity than real pearls.

**Test Questions**

71. Name two heavy liquids which would be useful in separating diamond from white sapphire.
72. How many crystallographic axes has a crystal of emerald?
73. What is the Beilby layer?
74. Give the names of two transparent stones whose refractive index cannot be measured.

CHAPTER XV

CORAL, AMBER, JET

CORAL

A GEM which ranked high with the ladies of the Victorian era, coral is yet another substance which is derived from the secretion of calcium carbonate and other matter by animal life. Coral is actually the axial skeleton of the coral polyp. Many coral polypi produce "coral," but it is only in one particular member of the family that the skeleton produces the comparatively hard rose-coloured material known to jewellers as "Precious coral." This member of the coral family is known as *Corallium nobile* or *Corallium rubrum*, and, like most other corals, lives in colonies; the countless skeletons together assume a tree-like form. They are fished from the warm waters of the Mediterranean.

The composition of coral is roughly, calcium carbonate in the form of calcite (86-87 per cent); magnesium carbonate ( $\text{MgCO}_3$ ) ( $6\frac{1}{2}$ -7 per cent); organic matter ( $1\frac{1}{4}$ -3 per cent) ferric oxide ( $\text{Fe}_2\text{O}_3$ ) ( $\frac{3}{4}$ -2 per cent); calcium sulphate ( $\text{CaSO}_4$ ) ( $1\frac{1}{4}$ - $1\frac{1}{2}$  per cent); phosphates, silica and water (small quantities). The hardness is about  $3\frac{1}{2}$ ; the specific gravity, 2.6-2.7. The fracture is uneven or splintery and the colour varies from pure white to dark red. The various shades have different names applied to them in the trade; these may be summarized as follows:—

<i>Bianco</i>	...	...	pure white.
<i>Pelle d'angelo</i>	...	...	pale flesh pink (angel's skin).
<i>Rose pallido</i>	...	...	pale rose.
<i>Rosa Vivo</i>	...	...	bright rose.
<i>Secondo colore</i>	...	...	salmon colour (second colour)
<i>Rosso</i>	...	...	red.
<i>Rosso scuro</i>	...	...	dark red.
<i>Arciscuro or Carbonetto</i>	..	..	very dark red, often called ox-blood red.

Coral effervesces with acids, due to its carbonate of lime content, and this is a practical method of testing, as all imitations are unaffected by acid. Coral, however, might be used as a simulation for pink pearl, in which case the acid test would not apply; but careful note of the appearance and lustre, which are very different, will distinguish the one from the other. Coral is occasionally stained before being placed on the market, but the process does not seem to be permanent.

Apart from the Mediterranean source there are further fisheries around the coast of Japan. There is also a black coral, obtained from the skeleton of the *antipathes spiralis*, which is fished in the Indian Ocean. This type is horny and not calcareous, and is prized by the natives who call it *akabar*. It is obvious that the constants of this type are much lower than that for true red coral. No literature appears to state what the constants are, but one might assume that they would be about that of conchiolin (S.G. = 1.34 about). A similar type of coral obtained from the Mediterranean is termed *giogetto*. Off the Cameroon coast there has been fished a blue coral which was known to the natives as *akori*. This is obtained from the *alopara subirolcea*.

#### OPERCULUM

For the sake of completeness some mention may be made of another material of organic origin and consisting of carbonate of lime and conchiolin. Known as *operculum* or *shell* (or *Chinese*) *cat's-eye*, but unlike the gem *cat's-eyes* of chrysoberyl or quartz, etc., they do not exhibit chatoyancy and their only claim to the title "eyes" is due to their circular shape and eye-like markings of green and brown on the whitish surface.

These objects are actually secreted by a mollusc known as the *Turbo petholatus*, which in appearance, both the animal and the shell, resemble an outsize in winkles. The operculum (Latin, meaning a lid) is the process secreted by the animal to act as a door to the mouth of the shell. In the common

winkle, this "door" is the well-known horny plate which is found attached to the animal, while in the Turbo the door or operculum is shelly and thick with a domed-shape outer surface. The base of these objects is flat and is covered by a brownish skin and shows spiral lines of growth.

The constitution is calcium carbonate in the form of radiating crystallites of aragonite, a small quantity of organic matter (conchiolin) and some water. The specific gravity ranges between 2.70 and 2.76. The hardness,  $3\frac{1}{2}$ . These shells, termed *topshells*, are found in the littorals of the tropic seas between Indo-China and the northern coast of Australia and the South Seas. These objects have little importance in jewellery.

#### AMBER

Compared with most of the materials used as precious and ornamental stones, amber is a youngster in geologic time, despite the fact that it is a fossil; whereas most gems had their genesis when this earth was a slowly cooling mass. Amber is the fossilized resin of certain coniferous trees which flourished in the geologic period known as Eocene, just previous to the great Ice Age, but at a time when animal life had already made its presence felt on this planet.

Transparent to opaque (bone) amber has as its most characteristic colour various tints of yellow and yellowish-red, although it may be found in shades of white, blue, red and also black, but these tints are rare. Amber is very soft, it has a hardness of only  $2\frac{1}{2}$  on Mohs's scale, about the same, or slightly harder, than a finger nail. The specific gravity lies between the limits 1.00 and 1.10, that is, it is just heavier than water. The index of refraction is 1.54. It exhibits negative frictional electricity, that is it will pick up small pieces of tissue paper after being rubbed briskly on a cloth. This effect, which was one of the first phenomena to be observed with relation to magnetism and electricity, gives amber the distinction of being the parent of electricity. Amber to the Greeks was known as "electron," hence the name electricity.

This frictional electricity effect must not be taken too seriously as a test for amber, as certain of the amber counterfeits may also show this. Amber, like most other gems, has several varieties, mainly characterized by the localities in which it is found, and one can do little better than to attempt to describe them in the order of their accepted importance.

**BALTIC AMBER** (*Succinite*). The most important of the amber-bearing localities is the Samland coast near Königsberg, East Prussia, and eastwards along the Lithuanian coastline, where the material is often washed up on the shores after storms and is also dredged from the shallow waters. This *sea amber*, as it is called, is washed out by wave action from an outcrop of amber-bearing earth beneath the Baltic Sea. Most important, however, is the method of open pit mining, where the amber is dug out of the glauconite sand known as "blue earth" (not to be confused with the "blue ground" of the Kimberley diamond pipes, which is a peridotite) by steam shovels. At the mine town of Palmnicken this *pit amber*, as it is generally termed, is washed in revolving cylinders with sand and water and graded into three groups, first those pieces which by size and clearness can be used directly as material for fashioning, this being termed *Block amber*; secondly, those pieces too small in themselves but which are clean enough to be used for *Pressed amber* (see later under "Artificial Treatment"); and thirdly, the remainder, all rough material, this being heated in retorts to obtain succinic acid, amber oil and a resin called colophony, used in making varnishes and lacquers. Amber burns with a smoky flame giving off a strong aromatic odour, hence the German name *Bernstein*, and being so light readily floats just below the surface of the sea, and so may be carried by the action of the tides and currents across the North Sea, where it is washed up on the shores of the East Coast of England and on the coastline of Scandinavian countries.

**BURMESE AMBER** (*Burmite*) is found near the valley of the Hukawng, not far from the jadeite mines in the

Myitkyina district of Burma. This material may be said to be the primary source of the so-called *Chinese amber*, but much Baltic amber is now shipped to China. Burmite is generally of a pale yellow colour and is usually not so clean as the Baltic material, the mineral calcite often being an inclusion.

SICILIAN AMBER (*Simetite*) is of a darker colour, reddish hues being more common. It is found in the district around the mouth of the Simeto river, Catania. This amber is often marked by a fine bluish fluorescence not unlike that seen on oil.

ROUMANIAN AMBER (*Roumanite*), a deeper coloured amber; brownish-yellow, brown, red and black are common colours. This amber is also often found to show fluorescence. The district where the material is found is in the province of Bazau in Roumania.

Amber has also been found in Australia, the United States of America and Canada, but these finds are mainly of academic interest.

ARTIFICIAL TREATMENT. Before commenting on those materials which simulate amber some remarks must be given concerning the artificial treatment of the genuine substance. Amber can be, and often is, stained to shades deeper in colour in order to suggest aged amber (true amber darkens with age to a pleasing reddish colour); various shades of green are sometimes developed, one might suppose to suggest jade. A black is also produced. Amber is thermoplastic; that is, it softens on heating at a temperature of about  $180^{\circ}$  C. Small pieces can then be pressed together to form a mass large enough to cut; this is commercially known as *pressed amber* or *ambroid*. It may readily be detected by its fluidal structure, sharp margins of the zones of slightly different clarity and the elongated form of the included bubbles, those bubbles seen in natural amber are circular in form. Cloudy amber is often clarified by careful heating in an oil of similar refractive index, such as *rape-seed* oil. This fills the many small bubbles which are the cause of the cloudiness.



## IMITATIONS

**COPAL RESIN.** A recent fossil resin, similar to true amber in colour and appearance, but differing in its chemical composition, is dug from the surface soil where it is mainly found, that is in Zanzibar and New Zealand. The New Zealand variety is perhaps better known as *kauri gum*. Another type of this recent resin is known as *gum anime*, and has at times been found containing the remains of insects. Found in rounded lumps, copal generally has a characteristic goose skin appearance on the outside; this, of course, does not help in its distinction when the resin has been cut and fashioned for jewellery purposes. The specific gravity and the index of refraction are much about the same as for real amber; therefore the methods of detection by refractive index measurements and density determinations, and this includes the use of salt solution as a heavy liquid, are of no use to detect copal. Certain writers have made the suggestion that as amber when heated evolves hydrogen sulphide ( $H_2S$  = sulphuretted hydrogen), a piece of blotting paper moistened with a solution of lead acetate (sugar of lead) turns black in the fumes; copal does not do this. What is, perhaps, a quicker test, is to apply a drop of ether (the liquid anæsthetic, not the all-pervading medium assumed to be that which propagates the electro-magnetic waves of light) to the specimen, when, if copal, a dull spot is left, there being no dulling of the surface on natural amber; copal is softer under the knife, also. Dr. L. J. Spencer, in his latest book, states that to be really certain that a specimen is amber, it must be tested chemically, and there are many workers who readily agree with him; anyway, this imitation is not met with as commonly as one might expect.

**GLASS** is much harder and feels much colder than amber (amber being a bad conductor of heat feels warm to the touch). The density of glass is much greater than amber, generally over 2. Yellow glass can usually be detected on sight.

PLASTICS. The more important amber imitations are made of the plastic resins. A general description of these has already been given in the chapter on imitations, and hence, a comprehensive discussion will not be given now. However, as there are one or two points which it is useful to note, a short reiteration of the types is called for. The *phenol* type of *bakelite* appears to be the most common form of amber imitation, but all the bakelite types are suitable. The *celluloids* and *casein* have also been found to imitate amber; however, like bakelite, their greater density allows them to be separated from true amber by the salt solution (ten level teaspoonfuls of common salt in a tumbler of water; S.G. = 1.12-1.14). When tested by a knife, celluloid peels, while bakelite is tough; amber chips or comes away as a powder. These plastic imitations may exhibit frictional electricity. With casein, a drop of nitric acid placed on the surface produces a blister or dull spot. The low density plastics *plexiglass* and *lucite* (S.G. = 1.18-1.19) could also simulate amber, here again the salt solution will separate; there is, however, the new plastic, *polystyrene*, which is understood to have a density of only 1.05. This might afford trouble. As it has not as yet been found as an amber substitute, and little seems to be known about its other properties, the question must be left at that.

## JET

Also of vegetable origin, jet is a variety of fossil wood allied to cannel coal. It takes an excellent polish and as a gem material enjoyed a popularity in Victorian times as a medium for mourning jewellery. As in the case of coal, jet is due to the change during long years of the wood of a coniferous type of tree, the forests of which had been long buried by geologic changes. The best known and only localities of any importance are at Whitby and in the neighbouring Yorkshire dales, where it is found in the shales of the Upper Lias; in the province of Asturia in Spain; and Colorado.

Jet has a low hardness,  $3\frac{1}{2}$  on Moh's scale; its density lies between the limits 1.10 and 1.40 (most generally between 1.30

and 1.35). The refractive index appears to lie between the limits 1.64 and 1.68; observed on a refractometer the shadow edge is vague and indistinct. Jet burns with a smoky flame like coal, but does not soil the fingers when handled. The material may be conveniently imitated by any of the plastics, particularly the bakelites, casein and even the hard rubber-vulcanite. The very superior and characteristic polish which is taken by jet serves to identify the genuine material from the plastics. The specific gravity of the latter may overlap the range given for jet, but in only one case, that of bakelite, does the refractive index also approximate.

For material of a black colour in the make up of jewellery jet has, in recent years, been replaced by the harder and more durable chalcedony which has been stained black. Scotch cannel coal makes an effective substitute and, lastly, pressed amber in which a black colour has been induced gives, owing to its excellent polish, a very fine simulation of jet. The low density of amber serves for conclusive discrimination.

### **Recapitulation**

Coral is organic in origin and consists of calcium carbonate, etc., with organic matter.

Amber is of vegetable origin, a fossil resin.

Amber may be stained, welded together by heat, and is best imitated by certain plastics and by a recent fossil resin known as copal.

Jet is also of vegetable origin and is allied to the common substance—coal.

### **Test Questions**

75. What difference is there between a stone cut as a marquise and one cut as a pendeloque?
76. What is the essential mineral constituent of pearl?
77. What is "The Mantle"?
78. Are cultured pearls higher or lower in density than the naturally formed pearls?

## CHAPTER XVI

# TORTOISESHELL, IVORY

### TORTOISESHELL

THIS attractive material, another substance which is rarely included in works on gem materials, consists of the epidermic plates covering the bony carapace of the *Hawksbill*, a marine turtle (*Chelone imbricata*) and does not, as its name would imply, come from the common tortoise. These plates or *blades*, as they are termed in the trade, are the actual *tortoiseshell* and names are applied to them, such as *cross-backs*, *mainplates*, etc. (fig. 54). The colour varies from warm yellows mottled with rich browns to a deep reddish colour and dark brown.

The refractive index is round about 1.55 and the specific gravity 1.26 to 1.35. The material is thermoplastic, hence pieces may be moulded together (at the temperature of boiling water). Tortoiseshell is ably imitated by many of the plastics, notably with the so-called plastic horns—casein. A thin veneer of the genuine material is sometimes attached to a background of suitable plastic. This gives a baffling counterfeit. The turtle is found in Oceania, particularly the island of Celebes, the West Indies and the Brazilian coast.

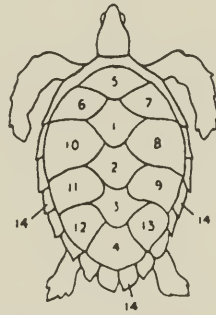


FIG. 54.—The Hawksbill turtle showing the blades of tortoiseshell. 1, 2, 3, 4, cross-backs. 5, 6, 7, 8, shoulder plates. 9, 10, 11, main plates. 12, 13, tail plates. 14, hoof.

### IVORY

Seldom included in gemological literature is the organic substance known as ivory, although as a material incorporated

in articles of adornment it has been known from the earliest times. Ivory is supplied by the tusks of the elephant, of the rhinoceros, the tusks and cutting teeth of the hippopotamus, the tusks of the walrus, the front teeth of the narwhal, the lower teeth of the cachalot and the tusks of the mastodon and mammoth (fossil ivory).

Elephant tusks are the animal's upper incisor teeth, and in the case of the male African elephant may weigh up to 150 lbs. The females have smaller tusks which are hollow for some distance up. Indian ivory, which may excel in quality the material from Africa, is smaller in size of tusk, weighing about 50 lbs. on an average. This type is also known as the Asiatic ivory; the Indian elephant country extends from Bengal to Burma and Sumatra. Mammoth ivory is found in Siberia and the Russia of the Urals, embedded in caves and often in ice. Although harder and more brittle than the recent ivory, the fossil ivory is often spoilt by cracks. Hippopotamus ivory is hard and white, while narwhal ivory contains flaws and cracks. Walrus ivory is somewhat rare and is in many respects coarser than the material from the hippopotamus.

Ivory consists of dentine and enamel, and a percentage of organic substance which may be keratin and/or albumin. The specific gravity lies between the limits 1.70 to 1.93 and the index of refraction (vaguely identified on a refractometer) is about 1.54. The hardness appears to be about two to three on the Mohs's scale and the fracture is splintery in character. The structure is very dense and a thin section (or peeling) viewed under the microscope shows a number of wavy lines reminiscent of the hachure lines seen on old maps to represent mountains. Ivory, when heated; produces fumes which are strongly alkaline in character (this may be ascertained by heating a small fragment in a test tube and using red litmus paper as an indicator); a drop of nitric acid tends to soften the surface of real ivory. Despite its dense character, ivory is somewhat porous and may thus be suitably stained. The pores appear to be filled with a gelatinous solution which contributes to the peculiar polish.

Ivory is simulated by all the better known plastics but the best imitation of an artificial nature is undoubtedly celluloid. The distinction is simple for celluloid peels under the knife, whereas ivory is tough, also the density of ivory is greater than celluloid. Bone which may be said to have a similarity to ivory has a greater density (1.94-2.10) and shows, when a peeling is viewed by microscope, many crack-like markings not seen in ivory. One of the most important substances which simulate ivory belongs to the vegetable kingdom and are the *corozo nuts* of commerce. These nuts are obtained from the *ivory nut palm*, the *Phetelephas marcocarpa*, which grows in the hot valleys around the Andes in South America. The nuts, similar to a large Brazil nut, are the kernels of the fruit. They are very hard when ripe and have a fine grained interior, white in colour. The density of this material lies between 1.38 to 1.42; the refractive index about 1.54. When heated, in contradistinction to ivory, the material gives a strong acid reaction. A peeling of vegetable ivory viewed under a microscope, or even a strong lens will do, shows a striated pattern of oval or torpedo shaped cells which appear to be connected together by filaments. More recently another sort of palm tree has produced a vegetable ivory, this is the *Doom palm* found growing, and also cultivated, in North and Central Africa. This "ivory," which is known botanically as from the *Hyphaene thebaica*, has the same characters as the *Corozo nut* "ivory."

### Recapitulation

Tortoiseshell is obtained from a turtle and not from a tortoise. The material is thermoplastic and hence pieces may be welded together.

Tortoiseshell is best imitated by the plastic casein.

Ivory is of the same nature as teeth and takes an excellent polish.

Ivory is best imitated by material from the kernels of certain palm nuts and by the plastic celluloid.

### Test Questions

79. Name three methods whereby X-rays are used in the testing of pearls.

80. What is the substance used to supply "iridescence" in the manufacture of imitation pearls?

81. Name two characteristics of the pink pearl.



## CHAPTER XVII

### UNUSUAL GEM-STONES

IN the chapter eight a short review was given of the mineral species supplying gemstones which have an importance, and are fairly common, in the jeweller's trade. There are, however, a number of other mineral species which produce transparent crystals which, when cut into suitable forms, produce gemstones vying in beauty with many of the gems better known to jewellers. Most of these are rare, and if found cut as gems, have usually been so fashioned for the requirements of collectors of the unusual, but it is a known fact that these gems may sometimes be found mounted in jewellery, often misnamed, as in appearance they might resemble in lustre and colour some very well-known gemstones. The descriptions of most of these gems follow.

**ANATASE.**—A native titanium oxide ( $\text{TiO}_2$ ); Tetragonal; *Colour*: brown to black; *H.* =  $5\frac{1}{2}$  to 6; *S.G.* = 3.82 to 3.95; *R.I.* = 2.493–2.554; *Lustre*: adamantine to metallic; localities are Switzerland, Brazil and North Carolina.

**ANDALUSITE.**—An aluminium silicate ( $\text{Al}_2\text{SiO}_5$ ); Rhombic; *Colours*: green, brown and red; *H.* = 7 to  $7\frac{1}{2}$ ; *S.G.* = 3.12 to 3.18; *R.I.* = 1.633–1.644; *Lustre*: vitreous; *Dichroism*: strong; localities are Brazil, Ceylon and Massachusetts. Andalusite may be mistaken for tourmaline of similar colour but may be differentiated by careful determination of the double-refraction, 0.011 for andalusite and 0.020 for tourmaline.

**APATITE.**—Calcium-fluorine phosphate ( $\text{Ca}_4(\text{CaF})(\text{PO}_4)_3$ ); Hexagonal; *Colours*: blue-green (termed MOROXITE), yellow-green (termed ASPARAGUS STONE), pink, violet, purple and colourless; *H.* = 5; *S.G.* = 3.15 to 3.23; *R.I.* = 1.63–1.64 to 1.64–1.65; *Lustre*: vitreous to resinous; *Dichroism*: feeble;



localities are Saxony, Bohemia, Maine, Burma, Ceylon and North Carolina.

**AXINITE.**—A complex calcium-aluminium borosilicate ( $(\text{Ca}, \text{Fe})_3\text{Al}_2(\text{B}, \text{OH})\text{Si}_4\text{O}_{15}$ ); Triclinic; *Colours*: brown, honey-yellow and violet; *H.* =  $6\frac{1}{2}$  to 7; *S.G.* = 3.27 to 3.29; *R.I.* = 1.67–1.68; *Lustre*: vitreous; *Dichroism*: very strong; localities are France, Tasmania and California. The name of the species is derived from the axe-like shape of the crystals. like shape of the crystals.

**BENITOITE.**—A barium-titanium silicate ( $\text{BaTiSi}_3\text{O}_9$ ); Hexagonal; *Colour*: sapphire blue; *H.* =  $6\frac{1}{2}$ ; *S.G.* = 3.64 to 3.65; *R.I.* = 1.76–1.80; *Lustre*: vitreous; *Dichroism*: strong; locality, San Benito County, California. Benitoite may be differentiated from sapphire by its lower specific gravity and by its large bi-refringence.

**BERYLLONITE.** — A sodium - beryllium phosphate ( $\text{NaBePO}_4$ ); Rhombic; *Colours*: colourless to pale yellow; *H.* =  $5\frac{1}{2}$  to 6; *S.G.* = 2.80 to 2.85; *R.I.* = 1.55–1.56; *Lustre*: vitreous; locality is at Stoneham, Maine, U.S.A.

**CASSITERITE.**—Tin oxide ( $\text{SnO}_2$ ); Tetragonal; *Colours*: red, brown, black and yellow. *H.* = 6 to 7; *S.G.* = 6.8 to 7.1; *R.I.* = 1.99–2.09; *Lustre*: adamantine; localities Cornwall, Bohemia, Saxony, Australia, Mexico and S. America.

**CHROMITE.**—An oxide of iron and chromium ( $\text{FeCr}_2\text{O}_4$ ); Cubic; *Colour*: opaque iron-black to brownish-black; *H.* =  $5\frac{1}{2}$ ; *S.G.* = 4.3 to 4.6; *Lustre*: metallic; locality Pennsylvania and Maryland.

**COBALTITE.**—A sulphide of cobalt and arsenic ( $\text{CoAsS}$ ); Cubic; *Colour*: opaque, silver-white; *H.* =  $5\frac{1}{2}$ ; *S.G.* = 6.0 to 6.4; *Lustre*: metallic; localities are Scandinavia, U.S.A., and England.

**DANBURITE.**—A calcium borosilicate ( $\text{CaB}_2\text{Si}_2\text{O}_8$ ); Rhombic; *Colours*: colourless and yellow; *H.* = 7; *S.G.* = 3.00; *R.I.* = 1.630–1.636; *Lustre*: vitreous; *Dichroism*: indistinct; localities are Madagascar, Burma, Japan and Switzerland. Danburite may resemble topaz, but its density is much lower (*S.G.* of Topaz = 3.53 *mean*).

**DIOPSIDE.**—A calcium-magnesium silicate ( $\text{CaMg}(\text{SiO}_3)_2$ );

Monoclinic; *Colour*: green; *H.* = 5 to 6; *S.G.* = 3.20 to 3.32; *R.I.* = 1.67–1.70; *Lustre*: vitreous; *Dichroism*: weak; localities are Italy, U.S.A., Brazil and Ceylon. A bright green chrome diopside is found in the *blue-ground* at Kimberley, S. Africa, and Burma; the latter being somewhat fibrous and therefore producing cat's-eyes. Alternative names for the species are ALALITE and MALACOLITE. A massive violet-blue variety is called VIOLANE and will be further mentioned under Ornamental Stones.

DIOPHASE.—A copper silicate ( $H_2CuSiO_4$ ); Hexagonal; *Colour*: emerald-green; *H.* = 5; *S.G.* = 3.3 (3.27 to 3.35); *R.I.* = 1.65–1.70; *Lustre*: vitreous; localities are Siberia, Chili and Congo.

ENSTATITE.—A magnesium silicate ( $MgSiO_3$ ); Rhombic; *Colour*: green; *H.* =  $5\frac{1}{2}$ ; *S.G.* = 3.26 to 3.28; *R.I.* = 1.66–1.67; *Lustre*: vitreous; *Dichroism*: very weak; localities are South Africa and Burma.

EPIDOTE.—A calcium aluminium silicate ( $Ca_2Al_2(AlOH)(SiO_4)_3$ ); Monoclinic; *Colours*: yellow, green, brown and red; *H.* = 6 to 7; *S.G.* = 3.25 to 3.50; *R.I.* = 1.73–1.76; *Lustre*: vitreous to metallic; *Dichroism*: strong; localities are Italy, France, Germany and Alaska.

EUCLASE.—A beryllium silicate ( $Be(AlOH)SiO_4$ ); Monoclinic; *Colours*: colourless, pale shades of green and blue; *H.* =  $7\frac{1}{2}$ ; *S.G.* = 3.05 to 3.10; *R.I.* = 1.65–1.67; *Lustre*: vitreous; *Dichroism*: weak; localities are Brazil, Russia, India and Tanganyika.

FIBROLITE.—An aluminium silicate ( $Al_2SiO_5$ ); Rhombic; *Colours*: pale blue and green; *H.* =  $7\frac{1}{2}$ ; *S.G.* = 3.25; *R.I.* = 1.65–1.67; *Lustre*: vitreous; *Dichroism*: strong; localities, Burma and Ceylon.

FLUORSPAR.—Calcium fluoride ( $CaF_2$ ); Cubic; *Colours*: colourless, yellow, green, violet, red, pink, blue and brown. BLUE JOHN is a massive variety of fluorspar which is found in the caves and lead mines at Castleton, Derbyshire. Sometimes known as DERBYSHIRE SPAR. *H.* = 4; *S.G.* = 3.18;

R.I. = 1.43; *Lustre*: vitreous; localities, England, France, S.W. Africa, Norway, Illinois and New Mexico.

HAMBERGITE.—A beryllium borate ( $\text{Be}_2(\text{OH})\text{BO}_3$ ); Rhombic; *Colour*: colourless; *H.* =  $7\frac{1}{2}$ ; *S.G.* = 2.25; *R.I.* = 1.55–1.62; *Lustre*: vitreous; locality, Madagascar.

HAEMATITE.—Iron oxide ( $\text{Fe}_2\text{O}_3$ ); Hexagonal; *Colour*: black; *H.* =  $5\frac{1}{2}$  to  $6\frac{1}{2}$ ; *S.G.* = 4.9 to 5.3; *R.I.* = 2.94–3.22; *Lustre*: metallic; localities, England, Germany, Spain, Scandinavia and Michigan.

HYPERSTHENE.—A magnesium iron silicate ( $(\text{Fe.Mg})\text{SiO}_3$ ) Rhombic; *Colour*: black with metallic spangles; *H.* = 5 to 6; *S.G.* = 3.3 to 3.4; *R.I.* = 1.67–1.68; *Dichroism*: distinct; localities, New York, Colorado and California.

IDOCRASE.—A complex calcium aluminium silicate ( $\text{Ca}_8\text{Al}(\text{AlOH})(\text{SiO}_4)_5$ ); Tetragonal; *Colours*: yellow, green and brown; *H.* =  $6\frac{1}{2}$ ; *S.G.* = 3.35–3.45; *R.I.* = 1.70–1.72; *Lustre*: vitreous; *Dichroism*: weak; Localities, Italy, Siberia, Norway, California and Colorado. Alternative name. VESUVIANITE. A green compact variety resembles jade and is known as CALIFORNITE, while CYPRINE is a greenish-blue variety, containing copper. A yellowish-brown variety from New York State is called XANTHITE.

IOLITE.—A hydrated magnesium (iron) aluminium silicate ( $(\text{M}_9\text{Fe})_4\text{Al}_8(\text{OH})_2(\text{Si}_2\text{O}_7)$ ); Rhombic; *Colour*: violet-blue; *H.* = 7 to  $7\frac{1}{2}$ ; *S.G.* = 2.58 to 2.66; *Lustre*: vitreous; *Dichroism*: strong; localities are Ceylon, India, Burma and Madagascar. Alternative names for the species are CORDIERITE, DICHROITE and the incorrect term "WATER SAPPHIRE."

KORNERUPINE — Magnesium aluminium silicate ( $\text{M}_9\text{Al}_2\text{SiO}_8$ ); Rhombic; *Colours*: colourless, brown and yellow, blue and green; *H.* =  $6\frac{1}{2}$ ; *S.G.* = 3.27 to 3.32; *R.I.* = 1.66–1.67; *Lustre*: vitreous; *Dichroism*: strong; localities are Madagascar, Ceylon, Saxony and Greenland.

KYANITE.—An aluminium silicate ( $\text{Al}_2\text{SiO}_5$ ); Triclinic; *Colours*: green, sky-blue, and colourless; *H.* = 5 to 7 (varies with direction); *S.G.* = 3.55 to 3.67; *R.I.* = 1.71–1.72; *Lustre*: vitreous; *Dichroism*: marked; localities are India,

Brazil, Switzerland, North Carolina and Kenya. Sometimes spelled **CYANITE**.

**MARCASITE**.—Iron disulphide ( $\text{FeS}_2$ ); Rhombic; *Colour*: brass yellow; *H.* = 6 to  $6\frac{1}{2}$ ; *S.G.* = 4.8; *Lustre*: metallic. The “marcasite” of the jewellery trade is really **PYRITES**, or merely cut steel or white metal.

**MOLDAVITE**.—A silica glass found in Bohemia and Moravia. It is amorphous and of green colour. Alternative names are **WATER CHRYSOLITE** or **BOTTLE STONE**. Moldavite is not unlike obsidian. *H.* =  $5\frac{1}{2}$ ; *S.G.* = 2.3 to 2.5; *R.I.* = 1.48 to 1.50.

**OBSIDIAN**.—A volcanic glass. Amorphous, with colours of black, red, brown and green. *H.* =  $5\frac{1}{2}$ ; *S.G.* = 2.3 to 2.5; *R.I.* = 1.50; localities, Oregon, California, New Mexico, Colorado, Wyoming.

**PHENAKITE**.—A beryllium silicate ( $\text{Be}_2\text{SiO}_4$ ); Hexagonal; *Colours*: colourless, pale yellow and pale pink; *H.* =  $7\frac{1}{2}$  to 8; *S.G.* = 2.95 to 3.00; *R.I.* = 1.65–1.66; *Lustre*: vitreous; localities are Russia, South America, Colorado and Maine.

**POLLUCITE**.—A caesium aluminium silicate ( $\text{H}_2\text{Cs}_4\text{Al}_4(\text{SiO}_3)_9$ ); Cubic; *Colour*: colourless; *H.* =  $6\frac{1}{2}$ ; *S.G.* = 2.86; *R.I.* = 1.51; *Lustre*: vitreous; localities are Maine and Isle of Elba.

**PYRITES**.—Iron disulphide ( $\text{FeS}_2$ ); Cubic; *Colour*: brass yellow; *H.* =  $6\frac{1}{2}$ ; *S.G.* = 4.84 to 5.10; pyrites is the “marcasite” of the jewellery trade.

**RHODIZITE**.—A borate of aluminium and caesium ( $\text{KAl}_2\text{B}_3\text{O}_8$ ); Cubic; *Colours*: pale green and pale yellow; *H.* = 8; *S.G.* = 3.40; *R.I.* = 1.69; *Lustre*: vitreous to adamantine; localities are Russia and Madagascar.

**RUTILE**.—Titanium oxide ( $\text{TiO}_2$ ); Tetragonal; *Colours*: red, brown and black; *H.* = 6 to  $6\frac{1}{2}$ ; *S.G.* = 4.2 to 4.3; *R.I.* = 2.62–2.90; *Lustre*: adamantine to metallic; localities Russia, Scandinavia, Italy, France, Georgia, North Carolina, Switzerland and Madagascar.

**SCAPOLITE**.—An isomorphous group of minerals which are, in the main, sodium-calcium-aluminium silicates and belong to the tetragonal system; *Colours*: yellow, pink and

blue;  $H. = 6\frac{1}{2}$ ;  $S.G. = 2.61$  to  $2.70$ ;  $R.I. = 1.54-1.56$  to  $1.55-1.57$ ; *Lustre*: vitreous; localities Burma, Madagascar, Brazil and Massachusetts.

**STAUROLITE.**—A hydrated iron-aluminium silicate ( $HFeAl_5Si_2O_{13}$ ); Rhombic; *Colour*: reddish-brown;  $H. = 7$  to  $7\frac{1}{2}$ ;  $S.G. = 3.4$  to  $3.8$ ;  $R.I. = 1.74-1.75$ ; localities, Switzerland, South America, Georgia and Virginia. Owing to their tendency to crystallize in twins having a cruciform shape the crystals have a use as amulets. Sometimes called "cross-stone."

**WILLEMITE.**—A zinc silicate ( $Zn_2SiO_4$ ); Hexagonal; *Colours*: yellow, green, brown and reddish;  $H. = 5$  to  $6$ ;  $S.G. = 3.89$  to  $4.18$ ;  $R.I. = 1.69-1.71$ ; *Lustre*: vitreous to resinous; locality is at Franklin Furnace, New Jersey.

#### COLORING AGENTS IN QUARTZ:

**CHRYSOCOLLA:** A hydrated copper silicate of variable formula; probably amorphous; *Color*: green and greenish-blue;  $R. I.$  about  $1.50$ ;  $S.G. = 2.0$  to  $2.2$ ;  $H. = 2$  to  $4$ ; *Lustre*: vitreous to earthy; localities, Russia, Chile and Arizona.

**DUMORTIERITE:** A complex aluminum-borosilicate  $(Al(Al)_7(BOH)(SiO_4)_3)$ ; Rhombic; *Color*: blue and violet;  $R. I. = 1.67-1.68$ ;  $S.G. = 3.26$  to  $3.36$ ;  $H. = 7$ ; strongly dichroic; localities, California, Norway, Madagascar, France and South-west Africa.

#### Test Questions

82. Is jet of animal origin?
83. What heavy liquid is useful for the detection of amber?
84. What European country has an industry in the working of coral?

## CHAPTER XVIII

### ORNAMENTAL AND CURIO STONES

CUT in the cabochon style, or used for purposes where a flat or curved surface is suitable to the material, depending upon their use, ornamental and curio stones are divided into three classes by the Gemological Institute of America:

(1) *Ornamental stones* include those minerals sometimes fashioned as cabochons or as carved figures, cigarette boxes, ash trays, clock cases, etc. Some are massive varieties of better known minerals, certain of which have been previously described. Others, such as jade, lapis lazuli and others, are mentioned again because of their importance in this classification.

(2) *Decorative stones* are those never fashioned as cabochons or other gemstones but sometimes fashioned as carved figures, cigarette boxes, etc., and sometimes used as elements of architectural decoration, such as store fronts, wainscoting, columns and mantels.

(3) *Curio stones* are those fashioned as gemstones, usually cabochons, rather because of their unusual appearance or their attraction as souvenirs or curios than because of beauty or durability.

**MALACHITE.**—A hydrated copper carbonate ( $\text{Cu}_2(\text{OH})_2\text{CO}_3$ ); Monoclinic; *Colour*: green with a silky texture; *R.I.* = 1.65–1.90; *S.G.* = 3.74 to 3.95; *H.* = 4; *Lustre*: vitreous to adamantine; localities Russia, Chile, Belgian Congo, South Africa and Arizona. Malachite, like all carbonates, effervesces when acted on by an acid and is mainly fashioned as polished plates, or occasionally in cabochon forms.

**AZURITE.**—A hydrated copper carbonate, with a slightly

different formula to Malachite ( $\text{Cu}_3(\text{OH})_2(\text{CO}_3)_2$ ); Monoclinic; *Colour*: dark blue; *R.I.* = 1.73–1.83; *S.G.* = 3.77 to 3.89; *H.* =  $3\frac{1}{2}$  to 4; *Lustre*: vitreous; localities, Russia, Chile, S.W. Africa, Arizona and France. Sometimes known as CHESSYLITE, azurite, like malachite, is affected with acids.

AZUR-MALACHITE is malachite veined with azurite.

VIOLANE.—Near diopside ( $\text{CaMg}(\text{SiO}_3)_2$ ); *Colour*: violet-blue; *R.I.* = about 1.69; *S.G.* = 3.23; *H.* = 6; *Lustre*. waxy.

RHODOCHROSITE.—Manganese carbonate ( $\text{MnCO}_3$ ); Hexagonal; *Colour*: rose-red or yellow or brown; *R.I.* = 1.60–1.82; *S.G.* = 3.70 (about); *H.* = 4; *Lustre*: vitreous or pearly; localities, South and North America, Hungary and Saxony. Being a carbonate, rhodochrosite effervesces with an acid. Sometimes known as INCA-ROSE or ROSINCA, from a fanciful idea of its use by the Inca peoples.

RHODONITE.—A manganese silicate ( $\text{MnSiO}_3$ ); Triclinic; *Colour*: rose-pink; *R.I.* = 1.73–1.74; *S.G.* = 3.5 to 3.7; *H.* = 5 to 6; *Lustre*: vitreous; localities, Russia, Massachusetts and New Jersey. Unlike Rhodochrosite, this material does *not* effervesce with acid.

THULITE.—A calcium aluminium silicate ( $\text{Ca}_2\text{Al}_2(\text{AlOH})(\text{SiO}_4)_3$ ); Rhombic; *Colour*: rose-pink; *R.I.* = about 1.70; *S.G.* = 3.12; *H.* =  $6\frac{1}{2}$  (about); *Lustre*: vitreous. Found at Telemark, Norway, Washington, Massachusetts and Pennsylvania.

APOPHYLLITE.—A hydrated potassium calcium silicate ( $(\text{HK})_2\text{Ca}(\text{SiO}_3)_2\text{H}_2\text{O}$ ); Tetragonal; *Colours*: white ringed with shades of yellow, green and red; *R.I.* about 1.53; *S.G.* = 2.3 to 2.4; *H.* =  $4\frac{1}{2}$  to 5; *Lustre*: vitreous to pearly; localities, Germany, India, Sweden.

FLUORSPAR.—The calcium fluoride has been treated under the unusual gemstones, as the clear material has been fashioned into cut stones. The inclusion here is made on the knowledge that the material has been used for the carving of small figures, despite the easy cleavage of fluorspar. The greenish material resembles, to some extent, the greenish beryl, the



latter mineral is much harder, has a higher index of refraction and a lower density, and is doubly refractive.

		H.	R.I.	S.G.
FLUOR ...	...	4	1.43	3.18
BERYL ...	...	7½-8	1.57-1.58	2.70

LAPIS LAZULI has been treated under the lesson on species. It is included here as the material is often used for small *objets d'art*.

VARISCITE.—A hydrous aluminium-phosphate ( $\text{AlPO}_4 \cdot 2\text{H}_2\text{O}$ ); Rhombic; *Colour*: green; R.I. about 1.58; S.G. = 2.5 (about); H. = 4 to 5; *Lustre*: vitreous; locality, Utah. Alternative name, UTAHLITE.

WARDITE.—A hydrous aluminium phosphate ( $\text{Al}_2(\text{OH})_3 \text{PO}_4 + \frac{1}{2}\text{H}_2\text{O}$ ); Probably amorphous; *Colour*: light-green to bluish-green; S.G. = 2.77; H. = 5; *Lustre*: vitreous; locality, Utah.

ODONTOLITE.—A fossil bone or ivory-stained blue by vivianite, an iron-phosphate; *Colour*: blue; S.G. = 3.00 to 3.25; localities, France and Russia.

TURQUOISE has been dealt with in the lesson on the gem species. Its inclusion here is due to the use of this material in mosaics, etc. (especially by the Ancient Incas of S. America), and, as several of the materials mentioned under "ornamental stones," simulate turquoise; such materials are: ODONTOLITE, WARDITE, VARISCITE.

CHALCEDONY, another material which has already been dealt with under QUARTZ, ONYX, AGATES, etc., has a use as an ornamental stone. Notice must also be taken of the stained chalcedony.

SMITHSONITE.—A zinc carbonate ( $\text{ZnCO}_3$ ); Hexagonal; *Colour*: green and greenish-blue, also more commonly white or greyish and yellow; R.I. = 1.62-1.85; S.G. = 4.3 to 4.65; H. = 5; *Lustre*: vitreous to pearly; localities, Greece, Sardinia and New Mexico. The bluish-green variety is sometimes known under the name BONAMITE.

SLATE, an argillaceous material, is included here, as this substance is used for the so-called "black marble" used in the

manufacture of the Victorian and Edwardian styles of mantle clocks. The *S.G.* of slate lies between 2.81 and 2.86.

**LAZULITE.**—An iron (magnesium) aluminium-phosphate ( $H_2FeAl_2P_2O_{10}$ ); Monoclinic; *Colour*: blue; *R.I.* = 1.61–1.64, *S.G.* = 3.1 (about); *H.* = 6; *Lustre*: vitreous; markedly dichroic; localities, Sweden, Austria, North Carolina, Georgia and Brazil.

**SERPENTINE.**—An alteration product from the decomposition of olivine and other silicates; *Colour*: green (most commonly); *R.I.* = 1.49 to 1.57; *S.G.* = 2.5 to 2.6; *Lustre*: resinous or greasy; *H.* = 2½ to 4. Localities, Pennsylvania and Maryland. One variety, known as **BOWENITE**, simulates jade and is remarkable as having a higher *S.G.* (2.6–2.8) and is much harder, *viz.*, 5 to 6. "KOREA JADE" is a fancy name for serpentine.

The **JADES** have been previously discussed and only require inclusion here, as several of the minerals mentioned in this lesson simulate them (see p. 168).

**CALCITE (MARBLE).** — A massive calcium-carbonate ( $CaCO_3$ ); Hexagonal; *Colour*: white and other colours, veined in many shades; *R.I.* = 1.48–1.65; *S.G.* = 2.71; *H.* = 3.

Varieties of calcite used as ornamental stones include the following:

**ONYX MARBLE** is banded marble.

"**BRAZILIAN ONYX**," or "**MEXICAN ONYX**," is onyx marble of greenish colour.

Varieties of calcite used for decorative purposes include the following:

**EGYPTIAN MARBLE** is black, with yellow veining.

**SHELL MARBLE** consists of fossil shells.

**LUMACHELLA (Fire Marble)** is a shell-marble, from which a fire-like chatoyancy is emitted when the polished plate is turned in different directions.

**PARIAN MARBLE** is white.

**RUIN MARBLE** is yellow, with sections of a brown colour, due to the infiltration of iron oxide.

	<i>S.G.</i>	<i>R.I.</i> ( <i>mean</i> ).	<i>Hardness.</i>
Nephrite ... .. (Jade, part).	2.95 to 3.1	1.62	6½
Jadeite ... .. (Jade, part.)	3.30 to 3.50	1.66	6½ to 7
Pseudophite ... .. ("Styrian Jade")	2.60 to 2.85	1.57	2½
Prehnite ... ..	2.80 to 2.95	1.63	6 to 6½
Massive Grossular Garnet. ("South African or Trans- vaal Jade.")	3.40 to 3.50	1.73	6½ to 7
Serpentine ... .. ("Bowenite," "Verd- antique," "Antigorite," "Williamsite" and "Korea Jade.")	2.50 to 2.65	1.50 to 1.57	2¼ to 4 ("Bowenite" 5½ to 6)
Aventurine Quartz ... ("Indian Jade.")	2.65 to 2.66	1.55	7
Chalcedony (Chrysoprase). ("Swiss Jade.")	2.60 to 2.65	1.55	7
Microcline Feldspar ... ("Amazon Jade.")	2.54 to 2.57	1.53	6 to 6½
Idocrase ... .. ("Californite.")	3.35 to 3.45	1.72	6½
Smithsonite ... .. ("Bonamite")	4.30 to 4.65	1.62 to 1.85	5
Agalmatolite ... .. ("Figure-stone.")	2.785 to 2.815		2½
Saussurite ... ..	3.2		6½ to 7

Marble, like all calcites, effervesces with an acid.

**STEATITE.**—A massive variety of talc, a hydrated magnesium silicate ( $Mg_3(OH)_2Si_4O_{10}$ ); *Colour*: white or grey, tinged with green or red; *R.I.* = 1.54–1.59; *S.G.* = about 2.75; *H.* = 1, may be harder, due to impurities. Steatite, owing to its soapy feel, is often termed SOAPSTONE. The material is often used for carving small figures.

**AGALMATOLITE** may be soapstone (steatite) or a massive variety of the mineral PINITE; *Colours*: green, brown or yellow; *S.G.* = 2.78 to 2.81; *H.* =  $2\frac{1}{2}$  to  $3\frac{1}{2}$ . This material is also used for small carvings.

**GYPSUM (ALABASTER).**—A hydrated calcium-sulphate ( $CaSO_4 \cdot 2H_2O$ ); Monoclinic; *Colour*: white; *R.I.* = about 1.52; *S.G.* = 2.32 (pure) (2.2–2.4); *H.* = 2; *Lustre*: pearly to subvitreous; localities, England, New York and Italy.

**SATIN SPAR** may be either a fibrous variety of Gypsum, or a similarly fibrous Calcite (marble). Localities, New York and Michigan.

**PSEUDOPHITE.**—A hydrated silicate of aluminium magnesium; Monoclinic; *Colour*: grey-green to black; *R.I.* = 1.57; *S.G.* = 2.60 to 2.85; *H.* =  $2\frac{1}{2}$ ; localities, Styria, Switzerland, Italy, Austria, Norway and Sweden. Known commercially as "Styrian Jade."

**PREHNITE.**—A hydrated calcium aluminium silicate; Rhombic; *Colour*: light green, oil-green and yellow; *R.I.* = 1.62–1.65; *S.G.* = 2.80 to 2.95; *H.* =  $6-6\frac{1}{2}$ ; localities, Lake Superior District, New Jersey and France.

**GROSSULAR GARNET** (massive variety).—A calcium-aluminium silicate; Cubic; *Colour*: green; *R.I.* = 1.72 to 1.74; *S.G.* = 3.40 to 3.50; localities, South Africa, Oregon and California. Known also as "Transvaal or South African Jade."

**MICROCLINE (FELDSPAR).**—A potassium-aluminium silicate; Triclinic; *Colour*: green, brown, etc.; *R.I.* = 1.52–1.53; *S.G.* = 2.54 to 2.57; *H.* = 6 to  $6\frac{1}{2}$ ; localities, Colorado, North Carolina, Pennsylvania, Virginia and Russia. Sometimes termed "Amazon Jade."

**SAUSSURITE.**—A decomposed feldspar, white to greenish-

grey, and allied to Zoisite; *S.G.* = 3.2; *H.* =  $6\frac{1}{2}$  to 7; localities, Switzerland, and Lake Superior District.

**CHIASTOLITE.**—A variety of andalusite containing black carbonaceous inclusions, which usually have a definite arrangement resembling a cross. A curio stone. *H.* = 3 to  $7\frac{1}{2}$ .

**CHLORASTROLITE.**—Mottled greenish prehnite or related mineral with chatoyant effect. A curio stone, from Lake Superior region, especially Isle Royale.

**SILLIMANITE.**—Pale violetish blue, greenish or brownish gem mineral used as an inferior substitute for jade. Other colors sometimes cut as curio stones, or for collectors.  $\text{Al}_2\text{SiO}_5$ . *H.* = 6 to 7, or 7.5 for crystals. *S.G.* = 3.2; *R.I.* = 1.66 to 1.68. Blue variety sometimes distinguished as fibrolite; fibrous varieties as sillimanite.

**THOMSONITE.**—Popular curio stone occurring in Lake Superior district. Mottled or banded; sometimes orbicular. Red, yellow, green, white, grayish, brownish. Cut cabochon.  $2(\text{Ca}, \text{Na}_2)\text{Al}_2(\text{SiO}_4)_2\cdot 5\text{H}_2\text{O}$ . *H.* = 5 to 5.5; *S.G.* = 2.3 to 2.4; *R.I.* = 1.51 to 1.54.

**CALIFORNITE.**—A massive variety of IDOCRASE, which see.

The following species, mentioned in Chapter 9 as gem-bearing species, are also used as ornamental stones:

**BERYL.**—Semitranslucent green beryl has often been fashioned in the form of carved figures, when it sometimes appears to be similar to Green Fluorspar, which is often so carved. The greater hardness of green beryl is characteristic. The constants of green beryl are the same as for the gem varieties, *i.e.*, *R.I.* = 1.57–1.58. *S.G.* about 2.70, *H.* =  $7\frac{1}{2}$ –8. Localities, California, North Carolina, Maine.

**QUARTZ.**—Rock crystal and Rose quartz is used for carvings, while aventurine quartz containing flakes of chromium mica is termed "INDIAN JADE." Constants as for crystalline quartz.

BLUE JOHN is a massive variety of the mineral FLUOR-SPAR, which is used for small ornamental objects.

LABRADORITE (FELDSPAR) a variety of plagioclase, showing a play of colour due to lamellar twinning.

***Test Questions***

85. May amber be stained?
86. Is the coral polyp an animal or a vegetable?
87. Jet comes from Japan. Coral is found in Germany. Amber is obtained from Spain. Correct these statements if necessary.

*Answers to Test Questions*

1. Coral is formed by animal agency (the coral polyp), hence is not a mineral.
2. No, not necessarily, for emerald material is fairly common, but material of same size and good colour and free from flaws is extremely rare.
3. In crystals the internal molecular structure has an orderly arrangement, whereas, in glass, there is no such order.
4. The tetragonal system has one axis of a different length. In the cubic system all axes are equal.
5. Cubic, Tetragonal and Rhombic.
6. Re-entrant angles.
7. Conchoidal.
8. (a) Hardness, Fracture and Cleavage; (b) Cleavage.
9. Diamond, Corundum, Chrysoberyl, Topaz and Spinel.
10. Suggest:—Emerald. Amethyst. Fire Opal.
11. Suspend in a heavy liquid and then find S.G. of liquid.
12. Fluorspar (S.G. = 3.18).
13. Zircon (S.G. = 4.7).
14. They would require too long a stem.
15. No. Porous stones, such as turquoise and opal, might absorb the liquid with detrimental results.
16. In the ultra-violet region.
17. Lustre is due to reflection at the surface of a medium. Sheen is due to reflections from inside the stone.
18. Black. Because the yellow rays which constitute the monochromatic light are in that region of the spectrum which is absorbed by the stone.
19. 0.011. Diamond is singly refracting, hence has no double-refraction.
20. "Fire" is the display of the spectrum colours due to dispersion and well seen in diamond.
21. The critical angle.
22. Suggest: Diamond, Zircon and Demantoid garnet.
23. Either monochromatic (sodium) light or a Nicol's prism.
24. Amount of double refraction.
25. Snell.
26. (a) A direction of single refraction in a doubly refractive stone; (b) Two.
27. (a) The Tully; (b) the Herbert Smith.
28. Suggest by the direct measurement method.
29. Tourmaline, Kunzite, Sphene.
30. No. The cause is the same.
31. Specific gravity = 4, hence Ruby.
32. (a) Specimen has a higher R.I. than the contact liquid used, or the range of the refractometer; (b) dirty stone or refractometer.



33. Correct answers are:—

R.I. = 2.42	S.G. = 3.52 = Diamond.
R.I. = 1.54-1.55	S.G. = 2.65 = Quartz.
R.I. = 1.72	S.G. = 3.61 = Spinel.
R.I. = 1.45	S.G. = 2.15 = Opal.

34. The habit of a crystal is the typical form that it takes, *i.e.*, ball-like, as in garnets, or prismatic as in beryl.

35. The bright red fluorescence lines in the deep red.

36. Fluorescence is the term used to describe the light produced by certain substances when they are irradiated with invisible ultra-violet rays, X-rays, etc. If the effect is continued after the removal of the exciting rays the after-glow is termed phosphorescence.

37. "Fire," or dispersion, is the power of a transparent medium to separate the spectrum colours.

38. Zircon, Church, in 1866.

39. Orange or red.

40. The Becke test.

41. Two.

42. Green garnet (demantoid); Green spinel; Green diamond.

43. Strain.

44. Suggest: (a) Diamond, topaz, euclase; (b) Diamond, sphene, demantoid, garnet; (c) Diamond, corundum, chrysoberyl.

45. Yes. By the spectroscope.

46. Spinel; singly refractive.

47. Thailand (Siam) = Ruby, Sapphire and Zircon.

Afganistan = Lapis lazuli, Ruby.

48. Yellow orthoclase; Moonstone; Albite moonstone; Sunstone and Labradorite.

49. Tourmaline.

50. The crystals have different terminations at each end.

51. Peridot.

52. Corundum and spinel.

53. Marc A. A. Gaudin.

54. (a) By fusing together small pieces of real stone a larger piece is recrystallized. This is reconstruction; (b) No.

55. The emerald filter, if synthetic spinel the residual colour will be reddish or orange, if aquamarine the colour will be seen greenish.

56. Boule.

57. It is very questionable if diamond has been made.

58. Stone with R.I. = 1.805 would be an almandine garnet, while that with an index of 1.665 would be a glass.

59. The specific gravity and the birefringence.

60. No, only those coloured by cobalt.

61. Ascertaining whether doubly or singly refractive by (a) polarising microscope; (b) by use of spinel refractometer or by ordinary refractometer and monochromatic light.

62. Durability of surface polish and edges owing to the greater hardness of the synthetic material.

63. Their extremely low specific gravity.

64. To give a hard-wearing face, or to give the crown resistance to a testing file, to a paste counterfeit.
65. Jasper stained with Berlin blue.
66. Suggest: Topaz, Zircon, Aquamarine, Purple sapphire.
67. Chalcedony.
68. Diamond and corundum.
69. Soudé emerald.
70. By the polariscope (observing whether the extinction at  $90^\circ$  is present or absent) or by the observation of a double shadow edge on taking a refractometer reading (in monochromatic light on a standard instrument or by using a spinel refractometer). This is only possible if the stone is within the range of these instruments.
71. Clerici's solution diluted with water to an S.G. of about 3.7; Retgers salt diluted with water to a similar density or by a solution of methylene iodide, iodine and iodoform, S.G. = 3.6.
72. Four. A vertical or principal axis and three lateral axes at right angles to the vertical axis and at  $60^\circ$  to each other.
73. The amorphous flow layer, minutely shallow, formed when a material is polished. This layer may recrystallize or remain amorphous. Diamond, alone among gemstones, does not produce a Beilby layer.
74. This question is in the nature of a "catch." While the refractive index of such stones as diamond and zircon could not be measured on a normal refractometer, this constant can be measured on a spectrometer by the method of minimum deviation. Even opaque and highly refractive metals can have the constant of refractive index measured by special means.
75. Both are modified brilliant cuts so that the outline is not circular.
76. Carbonate of lime =  $\text{CaCO}_3$ .
77. The mantle is the fold of skin, consisting of epithelium cells, which surrounds the animal.
78. In general higher.
79. (a) By a lauegram, *i.e.*, the diffraction pattern (b) by its fluorescent effect (c) by its shadow or skiagram.
80. Essence d'orient, the scales of small fish called the "bleak."
81. (a) High density; (b) absence of nacre.
82. No. Vegetable.
83. Salt solution.
84. Italy.
85. Yes, any colour.
86. Animal.
87. Jet comes from Spain, coral is found in Japan. Amber in Germany.

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