HANDBOOK OF GEM IDENTIFICATION

by

RICHARD T. LIDDICOAT, JR.

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Characteristic silk-like inclusions are shown in a photomicrograph of demantoid garnet.

Frontispiece

HANDBOOK OF
GEM
IDENTIFICATION

by

RICHARD T. LIDDICOAT, JR.,

Director
GEMOLOGICAL INSTITUTE OF AMERICA

With a Foreword by

DEAN EMERITUS EDWARD H. KRAUS, PH.D., SC.D.

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UNIVERSITY OF MICHIGAN

Published by the
GEMOLOGICAL INSTITUTE OF AMERICA
11940 San Vicente Boulevard, Los Angeles, California

FIRST EDITION
FIRST AND SECOND PRINTINGS
1947

SECOND EDITION
1948

THIRD EDITION
1951

FOURTH EDITION
1953

FIFTH EDITION
1957

SIXTH EDITION
1962

PRINTED IN THE UNITED STATES OF AMERICA

Foreword

Today jewelers and the general public are better informed concerning gems than ever before. In the United States, this is due in large measure to the wide dissemination of gemological information during the last quarter of a century through the publication of authoritative texts on gems, the formation of many mineralogical clubs, and especially through the activities of the Gemological Institute of America, founded in 1931, and of the American Gem Society, organized in 1934. For some time, however, it has been recognized that there is need for a manual describing in detail the various methods and procedures to be followed in the identification of gems. This need is now being supplied by Richard T. Liddicoat's "Handbook of Gem Identification."

By his excellent scientific training and his extensive experience at the Gemological Institute of America, Mr. Liddicoat is well qualified to author an authoritative handbook. Moreover, he has had the benefit of the counsel and advice of Director Robert M. Shipley and others at the Institute.

In the opening chapters, the essentials concerning the important properties of gemstones are described in a lucid manner. Manufactured stones and the instruments used for testing are discussed in several chapters. The main portion of the book is devoted to the tests and procedures to be followed in the identification of gemstones, which are grouped according to color. As the tests and procedures are outlined in great detail, there should be no difficulty whatever in following them. The book also includes useful tables of properties, a glossary, and various flow charts.

This handbook should prove to be very helpful in the making of accurate determinations of gemstones. It is a valuable addition to gemological literature, and will be welcomed by dealers in, and lovers of, gems.

Edward H. Kraus.

Ann Arbor, Michigan
July 21, 1947

Preface

Although many books have been written describing gemstones and their occurrence, there is a need for books which give both the jeweler and the layman with limited equipment an outline for making the simple and often conclusive tests that identify gems. If properly used this handbook will help to fill that need.

Several individuals offered valuable assistance in the preparation of this book. From his initial suggestion, which started the preparation to the reading of the final proofs, Robert M. Shipley proved unfailingly helpful. The author is also especially indebted to Ralph J. Holmes, Ph.D., for his many suggestions. George Switzer, Ph. D., contributed several ideas that have been incorporated. Several of the adaptations of mineralogical instruments and tests for the identification of gemstones were developed by Robert Shipley, Jr. Many of the methods and tests used in this handbook were developed by him. The majority of the photomicrographs of gemstone inclusions are those of Dr. Edward Gubelin,C.G., of Lucerne. Switzerland, who kindly permitted their use. With few exceptions, the line drawings were prepared by Lester Benson.

Richard T. Liddicoat, Jr.

Los Angeles, California
August 20, 1947

Preface to Fifth Edition

The major change from the fourth to the fifth edition is the addition of a description of the use of the spectroscope in gem testing. The ever-increasing number of separations in which this instrument is useful made a section describing its use essential in a book of this type.

The representations in black and white of the spectra of various gemstones as seen in a hand spectroscope are taken from the courses of the Gemological Institute and were made by Lester B. Benson, Jr.

Developments of major significance in gem identification since the last edition have been few. Although a major breakthrough occured with the synthesis of diamond by the General Electric Company, no material of a size or quality useful for jewelry purposes has been produced.

Suggestions for changes and additions by G. Robert Crowningshield, Lester B. Benson, Jr., John Ellison, Jeanne Martin and L. L. Copeland of the staff of the Gemological Institute were very helpful.

Richard T. Liddicoat, Jr.

May 14, 1957

Preface to Sixth Edition

In each of the previous revisions of this book, the changes were limited largely to new finds, new substitutes, and new tests and developments in instrumentation that had occurred since the previous edition. This time, Chapters VI, VII, IX, X, XI. XII, XIV, and XV were changed materially. and Chapter XIII plus all of the identification chapters were completely rewritten. These new chapters are based on a procedure in which the refractometer is the first instrument used in an identification.

So many substances that are seldom encountered by jewelers are often submitted for identification to the Gem Trade Laboratories and they appear in so many collections that their properties and descriptions were added to Chapter XV and the complete tables. However, the main portions of each identification chapter have not been burdened with details of these rarely encountered gem materials.

Robert Crowningshield, Bert Krashes and Eunice Miles. of the Institute's New York Gem Trade Laboratory, read and criticized each of the new chapters, making a number of valuable suggestions and comments. Joseph Murphy and Glenn Nord of the Los Angeles staff also made constructive suggestions. In the course of typing the manuscript and preparing it for the typesetter, Jeanne Martin, also a Graduate Gemologist, contributed many useful ideas; in addition, she took many of the new photographs.

The rewritten chapter on the spectroscope (Chapter XIII) has a new table of absorption spectra. The illustrations were prepared by Crowningshield. using a new technique for making realistic black-and-white reproductions of absorption spectra. Changes in the book were edited by Lawrence L. Copeland.

Richard T. Liddicoat, Jr.

October 1, 1962

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Chapter I

Introduction

To successfully identify gemstones, firsthand familiarity with many of their properties and the tests for determining those properties is essential. Gems, being mostly varieties of mineral species, are more or less easily identifiable because each mineral has a fairly constant chemical composition, as well as physical and optical properties which vary within rather narrow limits. Thus, by determining the characteristic properties of an unknown stone, it is possible to determine its nature without question.

The trained gemologist needs to consult only tables to catalog the results obtained from the tests he makes as a gemstone is identified. The jeweler who seeks to train himself to proficiency in identification needs much more assistance. Probably the most common errors by the beginner are occasioned by two tendencies: failure to include all possibilities, and failure to properly interpret the results obtained. This book was written for the beginner in a manner designed to correct these two failings before their inception. It was felt that the benefits to the novice would compensate for the necessary repetition that results.

The first part of this book is devoted to the important properties of gems and to their identification by various instrument tests. with full explanations of methods and results. While in many instances positive identification can be made with the simplest of instruments, more difficult tests are also described in detail.

The remaining portion of the book is devoted to a detailed step-by-step plan to classify gemstones correctly in each of the different colors in which important gems occur, with a sufficiently wide color range to satisfy any indecision as to colors on the part of the tester. There are also chapters covering the distinction between gems of natural and synthetic origin. Means of identification of other substitutes also are included. Complete tables of the properties of important gems, as well as many infrequently encountered in the jewelry trade, are contained in the appendix. Tables of the properties of gems of the color under discussion, with the variability of each property, are contained in each chapter on identification.

Many photographs and drawings supplement the text in order to clarify the tests. Numerous photomicrographs illustrate the appearance of gems of natural origin, as well as the man-made counterparts. Characteristic inclusions of various gems are also portrayed in photomicrographs to assist in making identifications based on their characteristic internal appearance.

Chapters describing the important tests prepare the reader for the use of the final identification portion of the book. There are seven sections devoted to the identification of transparent gemstones and their substitutes; three to nontransparent gemstones and their substitutes; and one section to the identification of natural and cultured pearls, and pearl imitations. Each section on the identification of gemstones follows a pattern based upon the recommended procedure for gem testing outlined in Chapter XVI.

Chapter II

The Nature of Gemstones

The Nature and Classification of Gem Minerals. With rare exceptions (amber, jet, pearl, and coral) the materials used for gem purposes are minerals. A MINERAL has been defined as a naturally occurring inorganic material of essentially constant chemical composition, usually possessing a definite crystal structure or orderly arrangement of its component atoms. Opal, which is generally regarded as amorphous; i.e., lacking a systematic arrangement of atoms, is an exception. Since each mineral species possesses a constant chemical composition and a characteristic crystal structure, it follows that each species will have a constant set of physical and optical properties. This constancy of properties renders the identification of gem materials possible. Amber and jet, although they occur within the earth, are not regarded as minerals since they have been produced through the agency of living organisms. To such organic materials mineralogists have applied the term MINERALOIDS. A ROCK is a mechanical intergrowth of two or more minerals. Lapis lazuli, consisting of lazurite, pyrite and sometimes calcite, is an example of a gem that is regarded as a rock rather than a mineral.

Mineralogists, in their description of minerals, employ a classification just as zoologists and botanists do in describing animals and plants. Since almost all gems are minerals, gemologists follow the mineralogical classification. Botanists and zoologists refer to genera, species and varieties of plant and animal life. The gemologist and mineralogist use the terms, GROUP, SPECIES and VARIETY. GROUP refers to two or more gem minerals that are similar in structure and properties, but not quite the same chemically. The individual members of a group are themselves SPECIES. All VARIETIES of a species have the same crystal structure, and the same chemical composition, but differ only in color. The color variations are usually due to the presence of minute traces of impurities. Thus, ruby and sapphire are color varieties of the gem mineral corundum. The garnet family is classed as a gemological group, since there are appreciable differences in the composition of the several types of garnet although all members of the group are identical in structure. The difference in color among the members of the garnet group is not due to small quantities of impurities (as in the case of ruby and sapphire), but is directly attributable to the basic chemical differences between the species of the garnet group.

Crystal Systems and Their Function in Determinations. The optical, physical, and all other properties of a mineral, are determined by its chemical composition and crystal structure. Minerals having a definite crystal structure are called crystalline, while those with no regular internal arrangement are known as amorphous. One of the few natural amorphous substances used as a gem is opal, but glass and several other imitations are also amorphous. All crystalline materials are assigned to one of the six different crystal systems, each mineral species occurring in only one of those systems. The crystal systems are: isometric (or cubic); hexagonal; tetragonal; orthorhombic; monoclinic; and triclinic. Diamond and spinel crystallize in the isometric system. Beryl (emerald and aquamarine) and corundum (ruby and sapphire) crystallize in the hexagonal system. Zircon crystallizes in the tetragonal system. Gems crystallizing in the orthorhombic system are topaz and chrysoberyl. Commonly encountered monoclinic gems are the jades and precious moonstone (orthoclase feldspar). Gems that crystallize in the triclinic system are turquoise and labradorite feldspar.

Differences in chemical composition and internal structure give the various gems properties that differ from each other markedly, and thus enable the jeweler to identify the various species. Gems that crystallize in the isometric system and those that are amorphous are known as isotropic; that is, they are singly refractive. Gems that crystallize in the other five crystal systems are doubly refractive; i.e., they possess the property of breaking up a beam of light into two rays as it passes through the substance.

Knowledge of the crystal system of a gem is important because many of the properties used in identification are related to the crystallization of the material. Familiarity with crystal forms and habits is also a valuable aid in the identification of rough gem materials. On the basis of the optical properties of a cut gem, it is often possible to decide in which system or group of systems the gem belongs. The determination of the nature of common crystal inclusions in a faceted gem provides a valuable clue to its identity. Since the shapes of small crystal inclusions seen within liquid inclusions in Colombian and Uralian emeralds are different, the trained observer is able to determine the source of the gem by recognizing the crystal form of these inclusions. Genuine spinel, for example, is characterized by minute octahedral inclusions. Any mineralogical or gemological text contains diagrams which will assist in determining the crystal system of rough gems.

Crystal Structure. Variations in chemical composition and crystal structure of gem minerals cause a wide range of physical and optical properties. The heavier the individual atoms, the greater will be the density of the material. Likewise, spacing of atoms within the structure will influence densities. Diamond and graphite are both carbon, but the density of graphite is only slightly more than half that of the diamond. This is a consequence of the relatively closely packed structure of diamond. This tightly packed structure of the diamond also accounts for its extreme hardness.

Identification of Unknowns. Since each mineral species has characteristic and fairly constant optical and other physical properties, it follows that the determination of these properties will make possible the identification of a gem of unknown nature. There are many properties that may be used to separate the various species, but the ease with which the several properties can be determined varies considerably. Dispersion is a difficult property to measure, but it can be determined. Resistance to fracture or to chemical corrosion are not only difficult to evaluate, but will cause damage to the gem by their application. Unlike the mineralogist, the gemologist is severely limited in the tests which can be applied to gem identification. Many of the principal methods of mineral identification require the partial destruction of the sample. The gemologist is obviously limited to the use of tests that will in no way harm the specimen, yet they must be conclusive and rapid. The tests that best fulfill the gemologist's requirements are those for refractive index, single or double refraction, pleochroism, specific gravity, and characteristic inclusions. The first four have long been the basis of gem identification.

Identification of the various natural gem species is based on accurate determination of optical and physical properties. Prior to the advent of the synthetic gemstone, no further tests were necessary to conclusively identify any gem. The introduction of the synthetic has greatly increased the difficulty of accurately identifying gem minerals since, by definition, not only the chemical composition but the crystal structure of a synthetic must be identical with that of the natural gem which it represents. As a consequence of this identity of composition and structure, the optical and physical properties of both the natural stone and its synthetic equivalent are essentially identical. Therefore the determination of the constant optical and physical properties does not distinguish between natural stones and their synthetic counterparts. Fortunately, the inclusions found in man-made gems are different from those found in gems of natural origin. In many instances. however, the synthetic gem is sufficiently well made to require high magnification to resolve its inclusions. Inasmuch as it is often necessary to examine gems under high magnification, the use of characteristic inclusions to distinguish between natural gem species as well as between artificial and natural gems is of great value to one who has become familiar with their appearance.

Chapter III

Cleavage, Fracture, and Hardness

Cleavage. The atomic pattern of a gemstone and the relative strength of the bonds between atoms determines the manner in which the stone may break or split. CLEAVAGE, which might be compared to the splitting of wood along the grain, is a gemstone's tendency to split along directions parallel to certain planes of atoms in its internal structure; it is dependent on the lack of cohesion between atomic planes in certain directions. Cleavage within a gem results in a flat, smooth break, and is described both by its relation to the crystal faces, or possible crystal faces, of the original crystal and by the ease with which the splitting occurs. The cleavage of diamond is parallel to the octahedral faces; its most common crystal form. The cleavage of topaz is described as perfect parallel to the base of its prismatic crystal form.

Since few gemstones are likely to cleave, presence of cleavage cracks within a gem may be of valuable assistance in its identification. GEMS WHICH CLEAVE EASILY ARE: diamond, the feldspars, spodumene (kunzite), and topaz. Beryl, garnet, quartz, and zircon do not cleave readily. Perhaps the most frequent use of cleavage in identification is in the separation of various varieties of the feldspar species from the varieties of chalcedony which may resemble them. Tiny breaks often present around the girdle of a cabochon are flat and have a vitreous luster on feldspar but are shell-like with a waxy luster on chalcedony.

The presence of cleavage in a gem is proof that the material is crystalline and is an indication of importance to the gem cutter, who both utilizes cleavage and guards against it in his work.

False Cleavage (Parting). A flat smooth break that occurs parallel to planes of weakness caused by repeated twinning is called parting or false cleavage. It is not uncommon in ruby and sapphire, of the important gemstones.

Fracture. Fracture, which may be compared to splitting across the grain of a wood, takes several forms which are described by their distinctive appearance. The following are the most common:

Conchoidal fracture presents a curved and shell-like appearance. Most gems show conchoidal fracture — glass perhaps to a greater extent than genuine stones.

Even fractures have a smooth appearance, but lack the regularity and single-plane appearance of cleavage.
Some types of quartz show even fracture.

Uneven fractures can best be described by likening them to the edges of broken pottery.
Almost any mineral or rock may exhibit uneven fracture.

Splintery fractures resemble the usual breaks seen in wood.
Splintery fracture is seen most often in hematite and in nephrite jade.

Fracture is of little use in identification. with two notable exceptions:

(1) Chalcedonic quartz and turquoise have the shell-like fracture common to most gems. but the luster on such fracture surfaces is waxy to dull, not vitreous as in other gemstones.

(2) Hematite may be distinguished from substitutes such as Hemetine[1] by its splintery fracture.

Hardness. The property of hardness, dependent upon cohesion, or the forces of attraction between atoms, may be simply defined as a material's resistance to scratching or abrasion. Since each gem has a characteristic hardness, the test for hardness often provides a valuable clue to the identity of a gemstone. The possi-

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[1] Trademark.

bility of damage to the stone, in the case of transparent gemstones, seriously limits the value of the test. In the determination of opaque gemstones, on the other hand, the test is often essential.

Mohs' scale, the standard scale of hardness in both mineralogy and gemology, comprises the following minerals arranged in order of decreasing hardness:

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

NOTE: Mohs' scale is one of relative hardness only. The difference in hardness between the materials listed is not equal.

The following intermediate values, supplementary to the figures given by Mohs, are useful in gemstone identification:

$8\frac{1}{2}$ Chrysoberyl
$7\frac{1}{2}$-8 Beryl
$7\frac{1}{2}$ Almandite garnet, zircon

In addition, several man-made materials such as carborundum $9\frac{1}{4}$, steel file 6-7, window glass $5\frac{1}{2}$, copper penny 3, are commonly utilized.

In making a hardness test, the jeweler should bear in mind that a gem of any given hardness will scratch another gem of equal hardness, and that it may vary with crystal direction.

Hardness Testing of Transparent Gemstones. The test should preferably be made upon the back of the stone. Since the back of a mounted gem near the girdle is not visible, a scratch from the hardness points or plate edges on the back will not detract from the beauty of the stone.

Caution: Hardness tests must be applied to transparent gemstones with great care. When other tests have narrowed the identification to one of two or three of the fragile gems, the chance of fracture or cleavage from the hardness test is too high to risk its use. In the identification of transparent gemstones the hardness test must be regarded as a last resort, to be used only when no other test remains from which to draw a conclusion.

Preferred for the test applied to transparent gemstones are HARDNESS PENCILS, OR POINTS, which are usually made of tubular steel with the hardness point set into the tube and ground to a fairly sharp point. As a rule, only points of hardness greater than 5 are used, since these encompass the gem range.

If it is evident that the material may be glass, the hardness test may be made with a broken-ended STEEL FILE, which has a hardness of 6 to 7, is tough, will scratch glass, and usually has sharper edges than hardness points.

If there are indications that the gemstone is one of the tougher transparent varieties, HARDNESS PLATES are often used for the test. These plates are small, polished rectangular pieces of the minerals listed in the Mohs' scale.

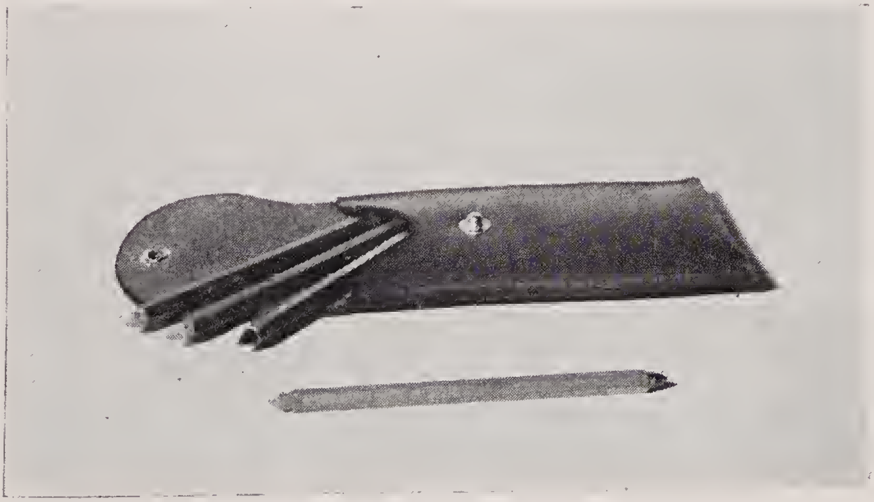

Figure 1

Set of hardness points, with points of hardness from five to ten.

To Make the Test with a Hardness Pencil or Point: With a gentle but firm touch, to avoid damage to the stone, apply the point to one of the back facets of the gem, as near the girdle as possible. Only a very short scratch is necessary. Wipe the gem carefully and examine it under the loupe to see whether the hardness point powders against the gem or actually makes a scratch.

Figure 2
Correct position and length of scratch on faceted gemstone.

It is often possible to apply the point along the relatively rough girdle of the gem, which offers a better testing surface and one on which the scratch may be hidden by the mounting.

To Make the Test with a Hardness Plate: In any test with hardness plates, start with the softer plates beginning with hardness 4 or 5. Attempt to scratch the hardness plate with the edge of the gem.

Caution: Since in testing gems in this manner against the plates of greater hardness a perceptible portion of the girdle might easily be ground down, and since the edges of the harder plates are usually sufficiently sharp to be used as hardness points, it is advisable to apply them as such against the back of the gem to avoid damage to the girdle.

The Hardness Test Applied to Opaque Gemstones. Since fewer tests are available for the identification of opaque gemstones than can be applied to transparent gems, the jeweler must often resort to the hardness test for a determination. Although either hardness pencils or plates may be used, hardness plates are often more helpful in testing opaque materials.

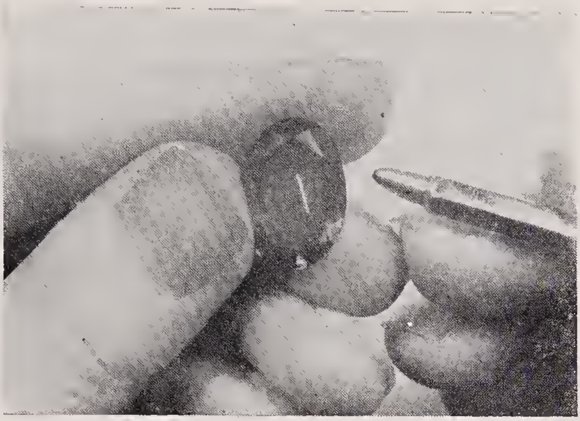

Figure 3

Incorrect hardness test—poorly placed and much too long.

To Make the Test with Either Hardness Pencils or Plates: Proceed according to the directions given for each in the preceding paragraphs. Less care is needed, since scratches on the back of the opaque gem are not visible after the stone has been mounted.

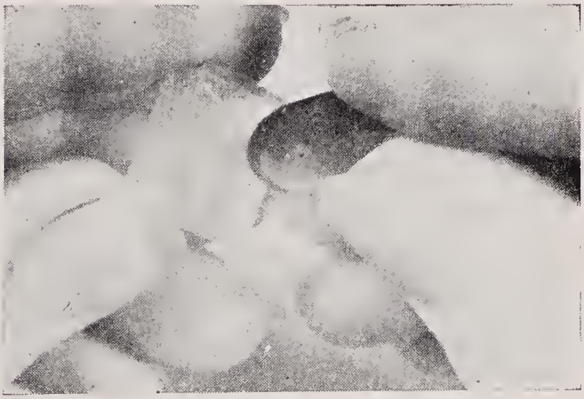

Figure 4

Hardness testing with a hardness plate.

Hardness Table

Diamond	10
Silicon carbide	9¼
Corundum & Syn.	9
Chrysoberyl	8½
Spinel & Syn.	8
Painite	8
Topaz	8
Taaffeite	8
Rhodizite	8
Beryl & syn. emerald	7½-8
Phenakite	7½-8
Zircon	7½
Almandite garnet	7½
Hambergite	7½
Euclase	7½
Gahnite	7½
Gahnospinel	7½
Rhodolite garnet	7-7½
Pyrope garnet	7-7½
Spessartite garnet	7-7½
Tourmaline	7-7½
Andalusite	7-7½
Iolite	7-7½
Staurolite	7-7½
Grossularite garnet	7
Quartz	7
Danburite	7
Dumortierite	7
Chalcedony	6½-7
Peridot	6½-7
Jadeite	6½-7
Andradite garnet	6½-7
Axinite	6½-7
Saussurite	6½-7
Idocrase	6½
Scapolite	6½
Kornerupine	6½
Pollucite	6½
Spodumene	6-7
Sinhalite	6-7
Epidote	6-7
Sillimanite	6-7
Cassiterite	6-7
Zoisite	6-7
Rutile & Syn.	6-6½
Microcline	6-6½
Orthoclase	6-6½
Nephrite	6-6½
Pyrite	6-6½
Benitoite	6-6½
Marcasite	6-6½
Prehnite	6-6½
Labradorite	6
Amblygonite	6
Leucite	6
Petalite	6
Hematite	5½-6½
Rhodonite	5½-6½
Beryllonite	5½-6
Anatase	5½-6
Brazilianite	5½
Enstatite	5½
Willemite	5½
Moldavite	5½
Thomsonite	5½
Opal	5-6½
Diopside	5-6
Glass	5-6
Strontium titanate	5-6
Lazulite	5-6
Lapis-lazuli	5-6
Turquoise	5-6
Sodalite	5-6
Chlorastrolite	5-6
Sphene	5-5½
Obsidian	5-5½
Datolite	5-5½
Bowenite (serpentine)	5-5½
Apatite	5
Scheelite	5
Dioptase	5
Smithsonite	5
Odontolite	5
Stibiotantalite	5
Apophyllite	4½-5
Zincite	4½
Kyanite	4-7
Variscite	4-5
Augelite	4
Fluorite	4
Rhodochrosite	3½-4½
Malachite	3½-4
Azurite	3½-4
Sphalerite	3½-4
Coral	3½
Conch pearl	3½
Calcite	3
Verdite	3
Black coral	3
Hemetine	2½-6
Pearl	2½-4½
Jet	2½-4
Pseudophite	2½
Agalmatolite	2½
Serpentine	2-4
Amber	2-2½
Copal	2
Alabaster	2
Stichtite	1½-2
Steatite (soapstone)	1-1½

Chapter IV

Specific Gravity

Value in Identification. One of the most definitive tests available to the gem tester is the accurate measurement of specific gravity. Despite its usefulness as a means of distinguishing between gemstones, few jewelers attempt to determine specific gravity. Since the measurement is easily made with equipment found in the average jewelry store, it should be a basic tool in the identification of unmounted gemstones.

Density and Specific Gravity. DENSITY is defined as the mass of any given material per unit volume. It is dependent upon the atomic weight or weights of the constituents and upon the atomic spacing of the material. Thus, the mass or weight of lead in one cubic foot greatly exceeds that of an equal volume of wood. Diamond is composed entirely of carbon, an element with a very low atomic weight. The relatively close atomic spacing of diamond, however, gives that gem a medium density. Both the silicon and the oxygen atoms of quartz have atomic weights greater than carbon, but its less compact crystal structure produces a smaller mass per unit volume than diamond.

The fact that one substance has a greater density than another is of little value in gem identification, unless a means of making exact comparisons is available. To make exact comparisons, it is necessary to compare the weights of equal volumes of materials. Since gems are seldom of the same size, their volumes must be determined first. The ratio of the weight of a gemstone to the weight of an equal volume of water gives a figure that can be compared to a similar value for any other gemstone. This ratio is called SPECIFIC GRAVITY. It is more accurately defined as the ratio of the weight of a substance to the weight of an equal volume of water at 4° Centigrade (the temperature at which density of water is the maximum). The variation of water's density from 4° to room temperature is so slight that it need not be considered in gem identification.

Comparing gemstones to an equal volume of water, we find that diamond, for example, weighs 3.52 times as much as the water. Amber is only 1.08 times as heavy as water in equal volume, while gold is 19.3 times heavier than water.

The specific gravity of each gem species is constant within fairly narrow limits. In a few instances, the specific gravity of two species will be nearly the same, or will overlap, but such instances are exceptional. It is therefore apparent that specific gravity can be used as a valuable aid to the identity of a gem.

The Hydrostatic Principle. To make a specific gravity determination, it is necessary to compare the weight of a gemstone to that of an equal volume of water. It might appear that it would be difficult to determine what constitutes an equal volume of water. The famed philosopher and scientist, Archimedes, determined that any material wholly immersed in water loses in weight an amount equal to the weight of water it displaces. Since a gem must displace a volume of water equal to its own volume, the weight of an equal volume of water must equal the stone's loss of weight when immersed in water.

Thus, if a gem is first weighed in air, then weighed when immersed in water, the difference in the two weights must be the weight of the water displaced — an amount of water which is equal in volume to the gem. Then the weight of the gem in air divided by the loss of weight when weighed in water must, by definition, be its specific gravity.

The Adaptation of the Jeweler's Diamond Balance for S. G.[1] Measurements. The diamond balance can easily be adapted to secure specific gravity measurements. A stand is placed so that its base rests under the weighing pan of the balance, and its arm extends up over the pan so that a water container can be placed over the pan, without touching the balance.

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[1] Specific gravity.

A wire is suspended from the arm of the balance which holds the weighing pan, so that it hangs into the liquid in the container which rests on the stand.

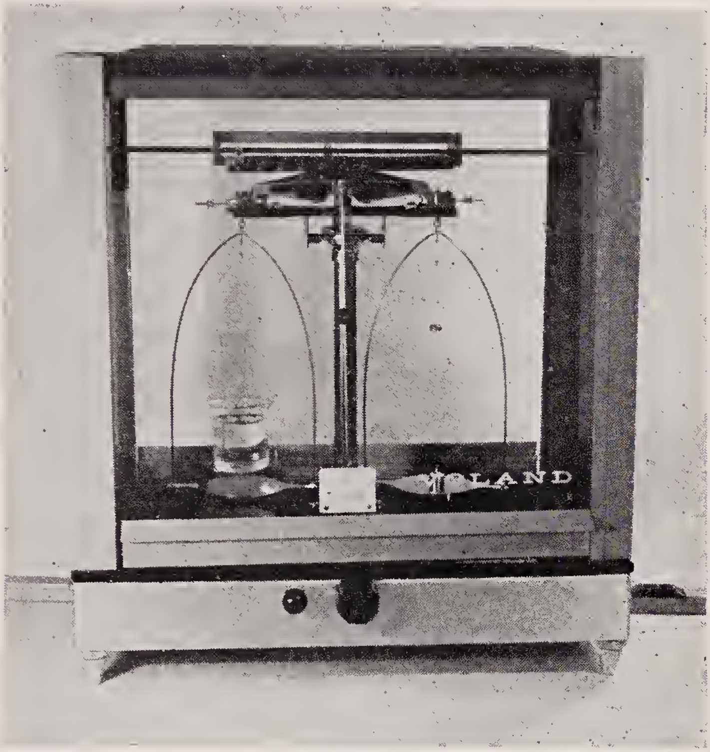

Figure 5

Close-up of diamond balance with specific gravity attachments.

The end of the wire that hangs into the water is bent into a loop or basket that will hold the gem to be tested. From the opposite arm of the balance a second wire is hung to act as a counterbalance to the wire suspended in the water. For the purpose of simplifying the calculation of specific gravity, the second wire should exactly balance the first, when the first wire is suspended in the water.

Use a longer wire for the counterbalance to the wire that holds the stone. Reduce the counterbalance in length very carefully, until it balances the wire which hangs into the liquid. This eliminates the necessity for taking into account the weight of the wire that holds the stone.

Sample Specific Gravity Determination by Means of a Diamond Balance. After having balanced a wire hanging in water on one side of the balance with a wire hanging in air on the other side, we make the following determinations:

The weight of a gem in air is four carats. Its weight in water is three carats. Using the formula,

$$\frac{\text{Weight in air}}{\text{Weight in air — weight in water}} = \text{Specific gravity}$$

$$\text{we have } \frac{4}{4-3} = \text{Specific gravity} = \frac{4}{1} = 4.0.$$

Detergent or "Carbona." When specific gravity is determined by means of the diamond balance, the surface tension of the water dampens the swing of the balanced wire loop basket so much that it is often difficult to obtain accurate determinations on small gems. To reduce the surface tension of water effectively, add a detergent, such as "Dreft" or "Vel" for which no extra computation need be made.

Jewelers often substitute the commercial form of carbon tetrachloride called "Carbona" in place of pure water to avoid the high surface tension problem. If this substitution is made, the tester must make allowance for the density of "Carbona"[1] (1.59) in the formula for obtaining specific gravity.

Thus, when weighing a gemstone in "Carbona" the formula is:

$$\frac{\text{Weight in air}}{\text{Weight in air — weight in liquid}} \text{x}1.59 = \text{Specific gravity}$$

Using the same example as that in which the weighing was taken in water, this change would be necessary: The weight of the stone in air was 4 carats; its weight in "Carbona" would be 2.41 carats. Inserting these figures in the above equation, we have the result:

$$\text{S.G.} = \frac{4}{4-2.41} \text{x}1.59 = \frac{4}{1.59} \text{x}1.59 = 4.0.$$

Because of its very low surface tension, specific gravity deter-

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[1] Carbona is now produced in two forms. Only the non-inflammable type should be used. To avoid error, chemically pure carbon tetrachloride (1.58) is recommended.

minations made with "Carbona" are usually more accurate than when water is used without adding a detergent. However, a detergent (loose powder of a type used in the home added in a quantity equal to about one-twentieth of the volume of water used) reduces the surface tension of water to nearly that of carbon tetrachloride.

Tolerances. The accuracy of a specific gravity determination on the diamond balance depends on the delicacy and accuracy of the balance, the skill and care of the tester, and the size of the stone tested. With water plus detergent, or carbon tetrachloride, an experienced and careful tester should be within ±.01 on stones of three or four carats or larger on a standard balance. The novice should use the following tolerances while becoming adept at the specific gravity determination: 3 carats or more, ±.10; 2 to 3 carats, ±.15; 1.25 to 2 carats, ±.20; .75 to 1.25, ±.25; and .50 to .75, ±.35. Below .50, a difference of .01 carat in either weighing may mean a difference of .50 in specific gravity, so even the most careful weighing on a standard balance may result in a determination far from the true figure.

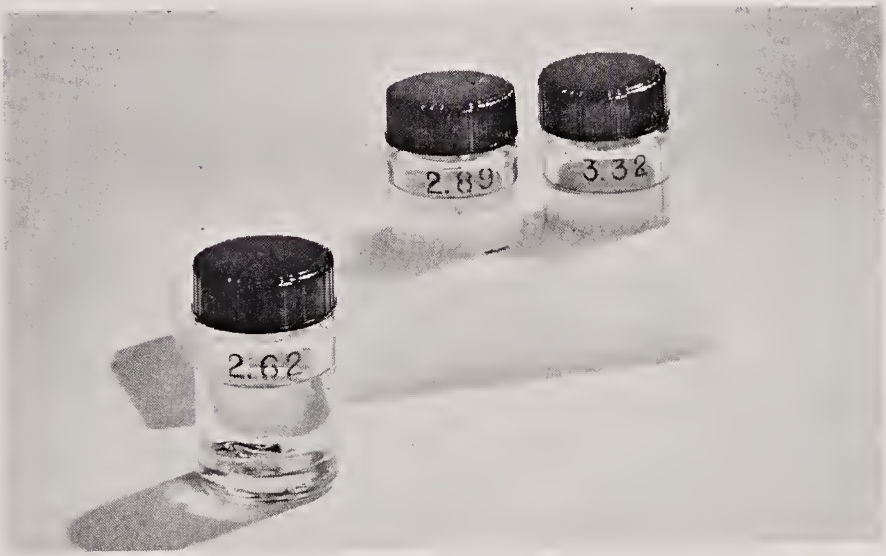

Figure 6

Three useful heavy liquids for specific gravity determinations.

limitation apparent in the balance method by which the results are unreliable for small stones (if the ordinary diamond balance is employed). Of the several liquids which may be used, the most practical are methylene iodide, bromoform, and Clerici's Solution. METHYLENE IODIDE is light yellowish-brown when fresh, but becomes darker, as iodine is set free by sunlight (a small piece of pure tin in the liquid prevents discoloration). In its pure form it has a density of 3.32 at room temperature.

BROMOFORM, a colorless liquid, gradually turns brown on exposure to sunlight as free bromine is released. Its density at room temperature is 2.9. Dark methylene iodide and bromoform is effectively lightened to its original color by removing the free iodine or bromine with mercury by drawing the metal and dense liquid repeatedly into an eye-dropper.

To determine the specific gravity of an unknown gemstone, using either methylene iodide or bromoform, place the gemstone gently in the liquid. *If the gem floats* it has a specific gravity less than that of the liquid, and the volume of the stone which remains beneath the surface of the liquid represents a volume of liquid equal in weight to the total weight of the stone. If 5/6 of a gem floating on a liquid is beneath the surface, the gem's specific gravity is 5/6 that of the liquid. If a small transparent glass beaker is used for this determination it is possible to arrive at a fairly close estimate of the proportion of the stone which is below surface. *If the gem sinks slowly*, its specific gravity is just greater than that of the liquid. *If it sinks very rapidly*, like a rock in water, the specific gravity is appreciably greater than that of the liquid. Caution: Tap a floating stone with tweezers to be sure the stone is not held by surface tension.

Both bromoform and methylene iodide may be diluted with toluene to produce liquids of lower density. Methylene iodide is often diluted to a density of 3.1, about that of tourmaline, and bromoform to 2.68 — a liquid in which beryl sinks slowly, and quartz just floats. Pure methylene iodide may be used to distinguish quickly between topaz and tourmaline, since topaz sinks (specific gravity 3.53) and tourmaline floats (specific gravity 3.06). In addition, bromoform diluted to about 2.62, a point between quartz and chalcedony, is useful in testing.

Clerici's Solution. Clerici's Solution is a mixture of thallium formate and thallium malonate which has a density between 4.2 and 4.3 in a saturated water solution at 70° F. The solution is transparent. In the saturated form of this liquid almost all transparent gems, with the exception of zircon, will float. Solutions of almost any density below 4.25 are easily made by diluting the solution with distilled water.

Clerici's Solution is much more expensive than methylene iodide or bromoform, but it is so valuable in testing that its use is recommended highly. For maximum effectiveness, many testers dilute the solution to the specific gravities of corundum (4.00), spinel (3.60), and diamond (3.52).

With all heavy liquids care is recommended to prevent the liquid from getting on the hands or clothes of the user. In addition, each liquid must be removed from stone and tweezers before the stone is placd in another liquid.

Almost every gemstone of importance will float in pure Clerici's Solution but liquids of proper density for the important gemstones may be made by dilution with pure water. With proper liquids, rapid and accurate specific gravity determinations are possible without the size limitations or the arithmetical or mechanical errors that occur in the diamond balance method.

Caution! Clerici's Solution is very poisonous and highly corrosive.

Suspensions. R. P. Cargille of New York City produces suspensions of metallic powder in methylene iodide with densities of up to 7.5. Such suspensions have the disadvantage of being nontransparent.

The specific gravity of gemstones is sufficiently constant to provide the gem tester with an important means of identification. It is not difficult to determine specific gravity by a variety of inexpensive but efficient methods.

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Chapter V

Refractive Index Determination

When a beam of light strikes the boundary surface between two transparent substances, such as between diamond and air, it is partly reflected. The law of reflection states that the *angle of incidence and the angle of reflection are equal and that the incident and reflected rays are in the same plane which is normal to the surface.* The reflection of an object in a mirror (Figure 7) illustrates this law.

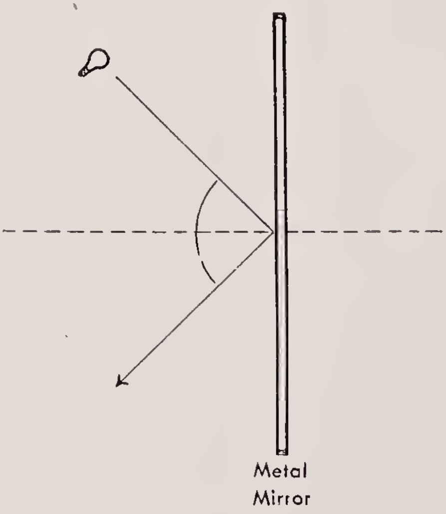

Figure 7
Reflection of a beam of light from a metal mirror.

Refraction. When a beam of light passes from air into another transparent material such as a gem, its velocity is reduced, and the beam is bent unless it strikes the surface of the material perpendicularly (at 90° to the surface). The ratio of the velocity of light in air to its velocity in the new substance is known as the refractive index of that substance. Light passing obliquely from air into an optically denser substance is bent toward the normal. The *normal* is an imaginary line perpendicular to the surface. (See Figure 8.) Light coming from a denser substance into air is bent away from the normal.

If light passes from one medium into another of unequal optical density in a direction perpendicular to their boundary, no deflection of the light takes place. Light that passed from a gem into air along a path parallel to X-X′ in Figure 8 would travel at an increased velocity in the air, but would suffer no bending at the gem surface. Light entering the gem from the air along a path X′-X would likewise continue in a straight line, but would be reduced in velocity.

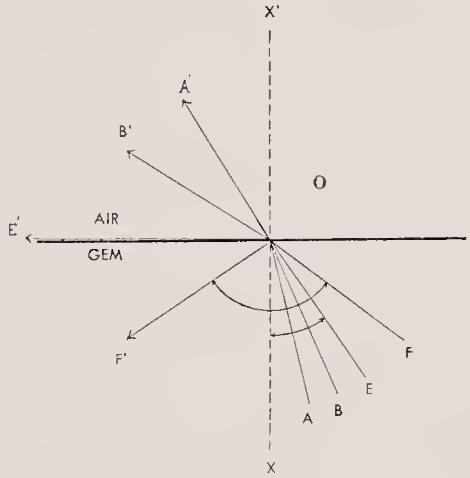

Figure 8

Refraction and total reflection.

A light beam originating at a point A in Figure 8 would travel the path designated A-A′. Light from point B, which travels along BO within the gem, would take a direction of OB′ when it passed into air. As the angle to XO increased for light beams that leave the gem at point O, the farther would the light be bent from OX′. The maximum possible deflection from OX′ would be reached when the light was bent at an angle of 90° as it entered the air. Such a condition is illustrated by path

EOF′ (Figure 8). Angle EOX is called the *critical angle* for the gem, since any light which impinges on the surface of the gem at point O, at an angle greater than EOX, would be totally reflected within the gem. Beam FOF′ illustrates total reflection. The size of the critical angle is dependent upon the *refractive index* of the material.

Refractive Index is defined as the ratio of the sine of the angle of incidence to the sine of the angle of refraction. It may also be defined as the ratio of the velocity of light in air to its velocity in a given substance. The higher the refractive index of the gem, the smaller its critical angle. Since the size of the critical angle is inversely proportional to the refractive index of any given substance, a measure of the critical angle will determine the refractive index. Gem refractometers are designed to measure critical angles and to translate the reading directly into a refractive index figure.

The Refractometer. *Of the many tests available to the jeweler who attempts to identify an unknown gemstone, the simplest to perform, and perhaps the most valuable in determination, is the measurement of the gem's refractive index on a refractometer.* The gem refractometer is an instrument which employs a very high-refractive-index glass hemisphere and measures the

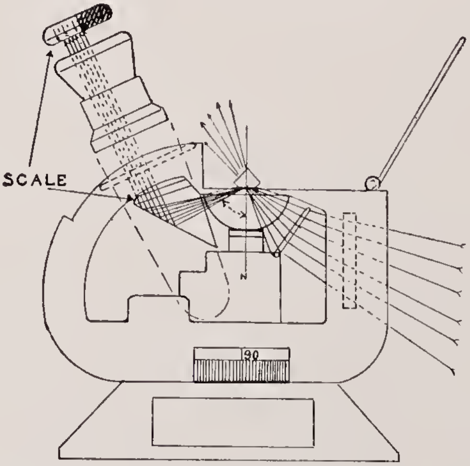

Figure 9
The optical system of the Erb and Gray Refractometer.

critical angle between the glass and the gem to be tested. The first gem refractometer was developed in Europe about 1885, and, until 1946, the only instruments of this nature were made in Europe.

The more recent models have a scale which automatically translates the critical angle reading into the refractive index. Light enters the back of the instrument, comes up through the glass hemisphere, strikes the gem, which is in optical contact with the top of the hemisphere, and is reflected through the lens system of the instrument to the eye. (See Figure 9.) All light which enters at an angle greater than the critical angle between the glass and the substance being measured is totally reflected from that substance and comes through the scale to the eye. The light which strikes the surface of the unknown gem at less than the critical angle is lost by refraction into the gem. Thus a shadow will be seen on the scale of the instrument up to the point of the critical angle, beyond which the scale will appear bright. (See Figure 16.)

The reading on the scale is easily distinguishable in white light because a narrow spectrum is visible at the dividing line between the shadowed and the bright portions of the scale, since there is a slightly different critical angle for each of the components of white light. If *monochromatic* light representing a very narrow spectral emission is used, no such spectrum appears; but instead, a very sharp division between the shadowed and the bright portions of the scale is visible.

The Rayner and several other refractometers magnify the contact between stone and glass several times, so that only a portion of the contact area is visible. If the eyepiece is removed from the Gem or the Erb & Gray and a 2X to 3X lens substituted, or if the Duplex is used without its supplementary lens, the contact between stone and hemisphere can be seen only slightly magnified. The late Lester B. Benson, Jr., discovered that a view of the whole contact area made it possible to obtain accurate readings on curved surfaces and facets with diameters of a millimeter or less from which no reading could be taken with conventional refractometry.

Types of Refractometers. The Rayner, made in England for a number of years, is the most expensive of the several gem refractometers available to the American jeweler. It employs a fixed, dense glass prism in place of a hemisphere. The instrument is practical, efficient, especially compact, and easily transported. Two important features of the latest model are: (1) a very large light portal at the back of the instrument, and (2) a cover that fits down tightly over the gem so that no confusing extraneous light strikes the stone. The Rayner Refractometer is available in the United States for approximately $110. B. W. Anderson and C. J. Payne, of the Precious Stone Laboratory of the London Chamber of Commerce, have designed two modifications of the Rayner Refractometer. One utilizes synthetic spinel and the other diamond in place of the dense glass prism. The advantage of the spinel lies in its low dispersion, which permits sharper readings for those gems which are lower in index than synthetic spinel. By using a liquid that has a refractive index of 2.05, zircon, all garnet species, and sphene, exhibit refractive index readings on the instrument with a diamond prism.

Figure 10
The Rayner Refractometer.

The G. F. Herbert Smith Refractometer, first manufactured in England in 1905, employs a segment of a hemisphere for the dense glass on which the gem to be tested rests.

The Tully, largest of the gem refractometers, employs a revolving hemisphere to facilitate the determination of birefringence and optic character. (See following Chapter.) The hemisphere has a very broad top surface on which the gem to be tested rests. Despite the large hemisphere, it is difficult to obtain readings from very large stones with a Tully since the metal surface, parallel to the top of the hemisphere, extends above it. If the gem is larger than the top of the hemisphere, the height of the metal prevents the gem from coming into contact with the glass.

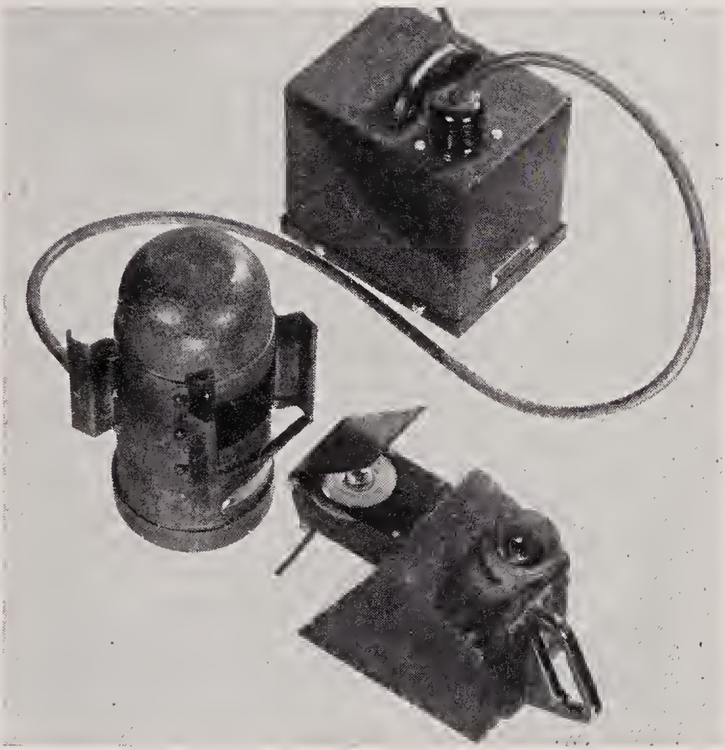

Figure 11

The Tully Refractometer with a Monochromatic Unit for light source.

The Erb and Gray is the first gem refractometer of American design and manufacture. Like the Tully, the first model had a revolving hemisphere. In its present form the Erb & Gray has an adjustable eyepiece mounted on a movable arm. By removing a set screw the eyepiece may be removed from its collar to facilitate spot readings on cabochons and tiny gemstones. This refractometer has proved to be exceptionally efficient for spot readings.

Figure 12

The Erb and Gray Refractometer

Because of the simple optical system of both models, readings are possible on both instruments on small gemstones and cabochon cuts that give no index reading by normal methods.

Gem Refractometer. The Gem Refractometer, manufactured by the Gemological Institute of America, is a tiny, inexpensive instrument employing a segment of a half cylinder of optically dense glass in a fixed position, and a movable eyepiece. Because there is little magnification, the contact between a stone not covering the hemisphere entirely and the liquid appears as a shadow covering only a portion of the scale, with the reading appearing as a conventional spectrum. (See Figure 14.)

The Duplex Refractometer. The most recently introduced refractometer, the Duplex, is the first designed expressly to read cabochons and tiny stones, as well as large stones with flat facets. The Duplex, designed by the late Lester B. Benson, Jr., K. M. Moore, and G. M. Johnson has a large slotted segment of hemicylinder instead of a hemisphere. It is the first instrument to employ a movable mirror instead of a movable eyepiece. Its dimensions are 6¾″ long, 3¼″ wide and 4″ high. A table of refractive indices is mounted on the side of the instrument.

The Gem Master Analyzing Refractometer, employing the Gem Refractometer with a monochromatic sodium lamp and polarizing equipment is described in the next chapter.

How to Use the Refractometer. The refractometer, the most useful instrument available for gem testing, is also the most delicate. Since the glass hemisphere or prism on which the gem

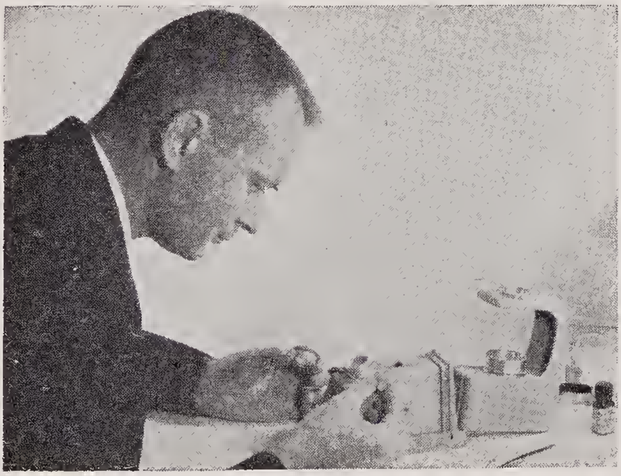

Figure 13

A spot reading being taken on a small cabochon is placed must have a refractive index well above that of the gem, it is necessary to use a glass that has a very high lead oxide content. The large percentage of lead oxide results in a glass not only very soft, but also easily corroded. The gems to be tested invariably will be much harder than the glass. Use every precaution to avoid scratching the glass by placing the gem on the instrument with care.

To produce an optical contact between the gem and the glass, a liquid of higher refractive index than that of the gem must be used. The liquid used on the refractometer is a saturated solution of sulphur in methylene iodide, with tetraiodoethylene added. Pure methylene iodide has an index of about 1.74. The addition of sulphur to the saturation point increases the refractive index to about 1.79. and the addition of tetraiodoethylene brings the index to 1.81.

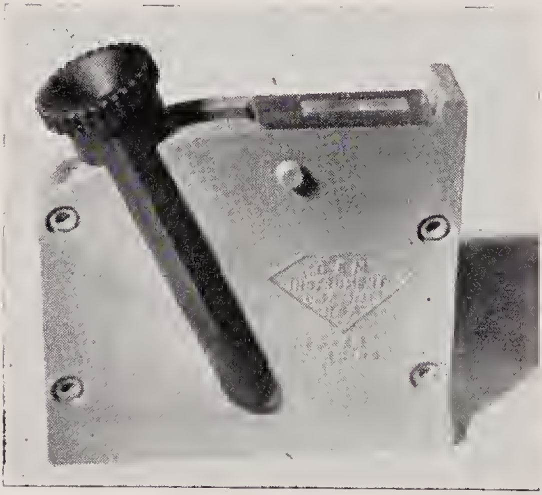

Figure 14
The Gem Refractometer.

Such a liquid is highly corrosive, and must not be left in contact with the glass any longer than it takes to make the refractive index reading—if it remains on the hemisphere, it oxidizes the glass, leaving a tarnish film that seriously reduces the efficiency of the instrument. The liquid must be removed from the hemi-

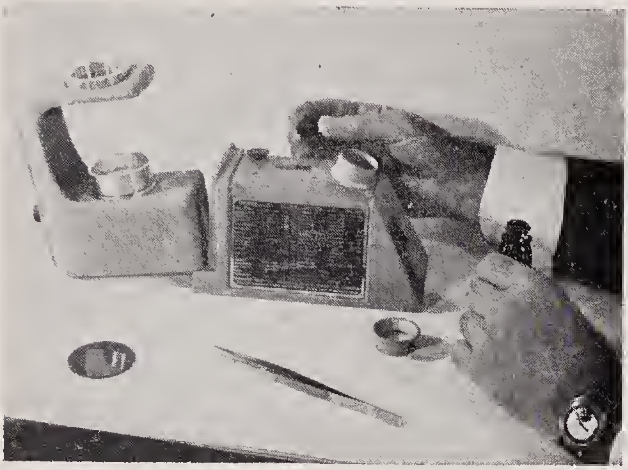

Figure 15 a

Careful transfer of high R.I. liquid to Duplex hemicylinder without touching the glass with the rod

sphere immediately after the reading is made. Since most tissues have harsh fibers that will scratch the glass surface in time, special lens tissue should be used to remove the high refractive

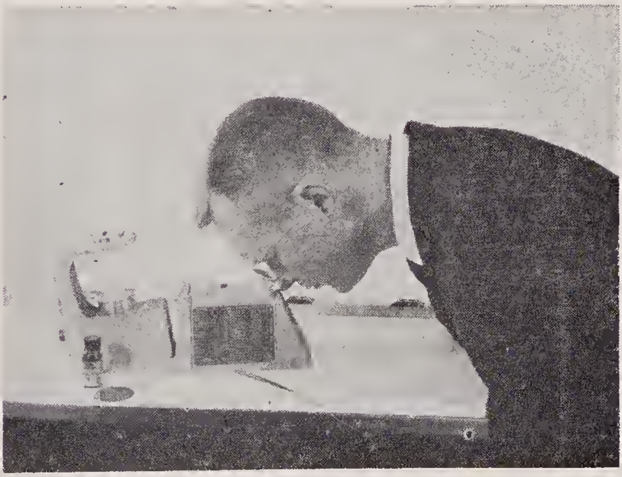

Figure 15 b

Taking a flat-facet reading on the Duplex with the Illuminator Polariscope as the light source index contact liquid. Observance of these precautions will materially prolong the life of the hemisphere surface.

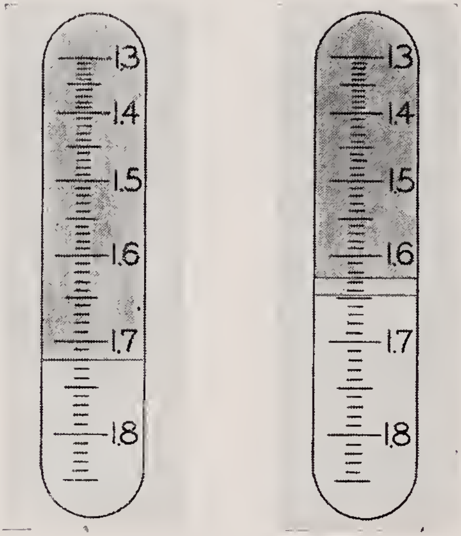

Figure 16
Left, refractive index reading for a singly refractive gem (spinel). Right, typical readings for the strongly doubly refractive tourmaline.

To determine the refractive index of a gem with a refractometer, first place a small drop of high index liquid of about 1/16 inch diameter on the refractometer hemisphere. Touch the glass rod, attached to the stopper of the liquid vial, against the mouth of the vial to remove excess liquid before transferring the drop to the hemisphere surface. Bring the rod only close enough to the hemisphere for the liquid to be transferred—*not so close that the rod touches the hemisphere.*

Carefully place the gem on the drop of liquid with the largest flat facet in contact with the surface of the hemisphere. Turn the light shield of the refractometer down to cover the hemisphere, but never far enough to touch the gem. If the instrument has no light shield. insert an opaque object between the stone and the light source.

Next, move a light source into position so that light enters the portal at the back of the instrument. A small microscope substage lamp with a blue ground-glass filter is excellent for this purpose, although almost any diffused light source is satisfactory. Many experienced jewelers simply direct the refractometer toward the nearest window, or toward an artificial light. Adjust the light or move the instrument so that the scale is well lighted and clearly visible.

If no clear reading is seen when the gem is first placed on the refractometer, move the stone slightly on the hemisphere. Be certain that there is no crystallized sulphur on the facet in contact with the glass. Change the position of the light to avoid missing a faint reading, and move your eye back and forth in relation to the eyepiece of the instrument. If the gem has too high an index to give a reading, the shadow should continue down the scale to the liquid reading at 1.81. If the shadow does not extend that far, but no clear reading is observed, remove the gem from the hemisphere to clean both the glass surface and the gem. If the gem has other large facets, try to read the refractive index from a second facet. Occasionally, a sulphur crystal, or dust, will prevent optical contact between the gem and the glass hemisphere. If no reading is obtained by this method, or if the reading is faint and questionable, check it by the spot method described on the next page. Many gemologists use the spot method to find the position of the reading as the first step in the determination of every refractive index reading.

If a reading is obtained, the scale will be relatively dark from its low number end to the reading, which will appear as a narrow spectrum dividing the dark and brightly lighted portions of the scale. If the gem is strongly doubly refractive, two such spectra may appear between the dark and brightly lighted portions of the scale. In the average doubly refractive gemstone the reading in white light appears as a broad single reading. Double refraction may be proved by rotating a Polaroid plate quickly before the eyepiece, causing the line to jump back and forth between the high and low readings.

With transparent gemstones it is possible to cover the light portal and direct the light source through the stone from above and behind it. This reverses the scale reading, since the high number portion of the scale is in shadow and the low end is brightly lighted. The spectrum denoting the reading is predominantly red in contrast to the blue and green of the normal reading.

If the gem has an index above that of the contact liquid (1.81), no reading will be visible, but the shadow will be unbroken up to the refractive index of the liquid, which is shown by a single line at 1.81 on the scale. No gem with an index that is higher than 1.81 will give a reading on the refractometer, but the shadow should extend to 1.81, the liquid index. By normal methods no reading will be observed on cabochon-cut gems, on very poorly polished gems, or on those without facets large enough to give a reading. However, such stones often yield readings by the spot method.

Spot Method. The effectiveness of the refractometer as a gem testing instrument was increased materially as the result of developments by Lester Benson[1] and Robert Crowningshield.[2] Benson discovered that removal of the eyepiece of the Erb and Gray Refractometer makes possible the resolution of the contact between gem and hemisphere as a small spot on the scale, the observation of which discloses readings on tiny gemstones, cabochons, and seemingly opaque materials not ordinarily readable on a refractometer. Crowningshield found that similar readings were possible on more complex refractometers if the scale were viewed at a distance of 18 inches or more from the eyepiece.

To obtain a reading by the spot method, a minute drop of contact liquid should be used. If the drop has a diameter of more than one half millimeter when resting on the gem surface or hemisphere, a portion of the liquid should be removed. After placing the gemstone over the droplet, the scale should be viewed from a distance of 18 to 24 inches (after moving the eyepiece arm out of the line of vision of the Erb and Gray or Gem Instrument refractometers). The proper eye-to-eyepiece distance, when using the

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1. Gems & Gemology, Vol. VI, No. 2, Summer 1948, page 35.
2. Gems & Gemology, Vol. VI, No. 6, Summer 1949, page 176.

Duplex Refractometer for this method, is nearer eight inches. For maximum accuracy, ultimately, the spot should be reduced to not more than two to three scale divisions with the stone resting on the hemicylinder. The eye is held over the center of the eyepiece and the mirror is moved to permit the scale to be scanned. The point of contact between gem and hemisphere will appear as a spot on the

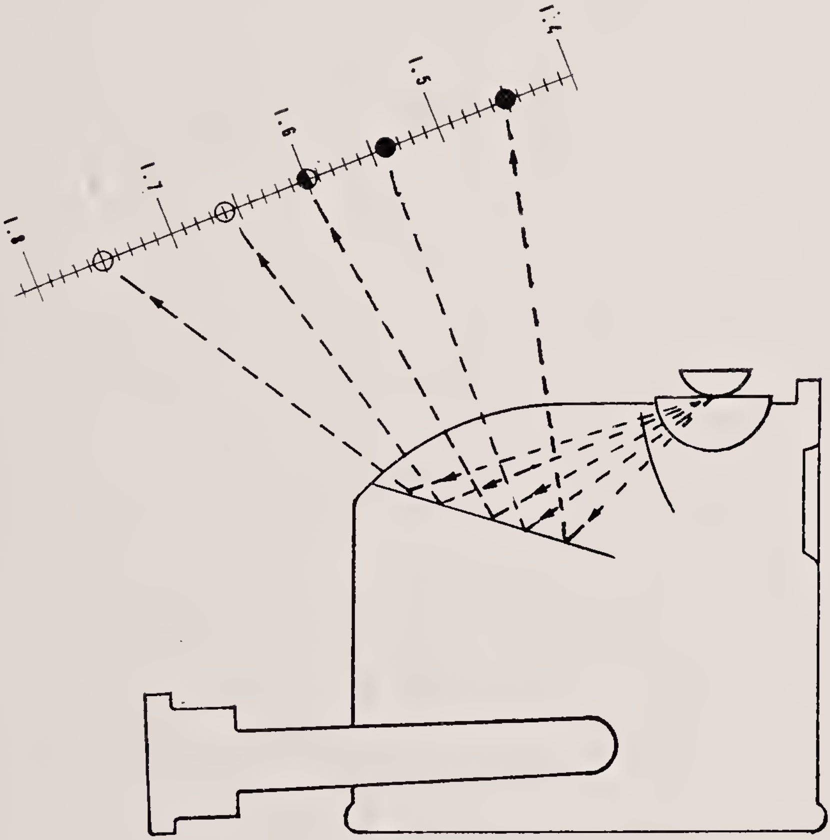

Figure 17

Schematic Diagram of a cabochon of 1.60 refractive index on the Gem Refractometer viewed from five angles. As the eye is moved, the spot remain dark at the low number end of the scale, until the reading approaches, when the edge of the shadow appears. The reading is made when the spot is half light and half shadowed.

scale, with the shape of the spot conforming to that of the gem surface (i.e., round or oval with cabochons, the shape of the facet of a faceted stone which is resting on the hemisphere). The spot appears to move in relation to the scale as the angle of observation changes. If the eye is looking directly down on the low number portion of the scale, and the gem has a high index. the spot will appear entirely dark. If the portion of the scale numerically higher than the reading is viewed directly, the spot will appear as a ring with a light center. At the point on the scale corresponding to the refractive index of the stone, the spot will be half dark and half light, often showing the conventional blue and green spectrum at the division between light and dark. (See Figure 17.) In general. the dark half is on the low number end of the scale. but curved surfaces, while conforming to the results described above otherwise. may give readings which are light on the low number half of the spot at the correct reading, and dark on the high number half.

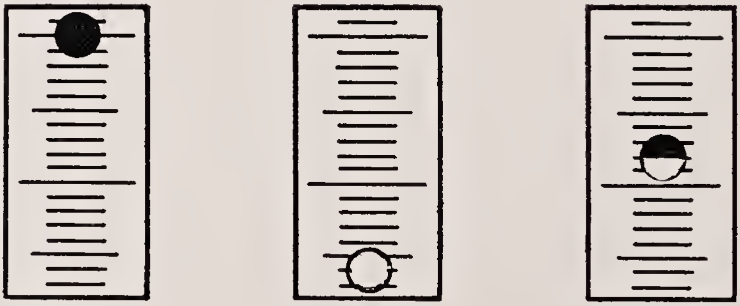

Figure 18

The scale from three angles showing a spot contact between a tiny flat surface and the hemisphere, with the correct reading position at the right.

When using any instrument but the Duplex, which was designed for the purpose, often the beginner finds difficulty in resolving the numbers on the scale at the same time the spot is in focus. On the Rayner, it is necessary to move the eye down to the eyepiece (or close enough to resolve the scale numbers). Then the eye is withdrawn slowly, while observing a number, until the spot is again in focus. When using the Erb and Gray, a 2X or 3X lens may assist the tester. Practice soon permits the gemologist to resolve spot and scale together.

Readings in White Light. If the light source used to obtain the refractive index reading is daylight, or an ordinary electric light source, the narrow spectrum representing the reading will appear predominantly blue and green, with a very narrow yellow band. The reading will correspond most closely to refractive index tables if it is read at the division between the yellow and green lines, since such tables usually give the index of the material for sodium light.

If the light portal is covered and light directed through the gemstone from above and behind, the high number end of the scale appears black and the reading appears as a red line across the scale between the black and lighted portion of the scale.

Readings in Monochromatic Sodium Light. The sharpest and most accurate readings on a refractometer are obtained with the aid of a monochromatic sodium light source. The yellow sodium light colors the scale with the same hue. Again the reading appears at the division between the shadowed and brightly

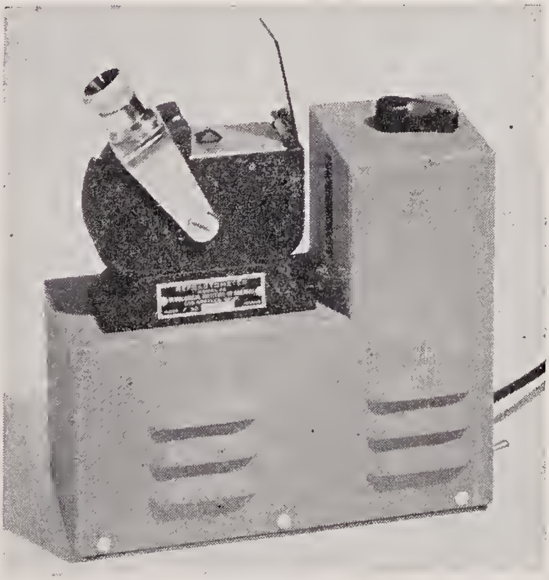

Figure 19
Monochromatic Unit with Erb and Gray Refractometer.

lighted portions of the scale, but with the sodium lamp the separation is very sharp. Since the sodium light is monochromatic, no spectrum interferes with a clear reading. A very sharp shadow zone demarcation is visible that may be read to ±.001. If the gem is doubly refractive, it is possible to read two indices on most facets. However, monochromatic light only sharpens readings visible in white light. It does not give one when none is obtained in white light.

Monochromatic sodium light can be provided by the G.I.A. Monochromatic Unit. (See Figure 19.) Salt placed in a candle or gas flame also produces a yellow light that is fairly satisfactory for refractometer determinations.

Mercury vapor lamps which are used with a filter to provide a long wave ultraviolet light source are useful for refractometer illumination if the filter is removed. The readings are almost exactly .01 lower than those in sodium light, but are nearly as sharp. If the .01 correction factor is applied, they are very satisfactory. A cardboard mask shaped to replace the Mineralight filter, leaving a small opening for the light to reach the refractometer light portal, provides a protection to the gemologists eyes.

A Wratten A red gelatin filter sharpens readings very effectively, but the result is usually about .005 above sodium light readings. Since most of the highly dispersive gem species have indices above the limits of the refractometer, the use of a red filter does not lead to gross errors of index when a .005 correction is used.

Cleaning the Refractometer. When the refractive index reading has been made, wipe the hemisphere surface clean with lens tissue. Apply a cleaning fluid, such as xylene, with lens tissue to prevent corrosion of the glass by the high index liquid. If the refractometer is not to be used again for a day or two, coat the surface with a thin layer of Vaseline as a further protection. Tarnish which in time covers the hemisphere surface can be removed if a paste made of cerium oxide powder and water is used as a polish and applied to the hemisphere surface with the fingertip. This should not be done until readings have become faint.

Other Means of Determining Refractive Index. Of the several other means of determining refractive index, none of which is as satisfactory as determination by the refractometer, the simplest is the approximate immersion method.

Determination of Approximate Refractive Index by Immersion. When a gem is placed in a liquid, the degree to which it is visible in the liquid depends upon the proximity of its refractive index to that of the liquid. (See Page 77 for list of immersion liquids.) As the indices of the gem and the liquid approach the same value, the outline of the gem becomes less distinct. If the gem is almost invisible, its index very closely approximates the index of the liquid. Thus, a hessonite garnet becomes almost invisible in methylene iodide, since the index of this garnet is about 1.74—the refractive index of the liquid. Topaz and tourmaline nearly disappear when placed in cinnamon oil, which has an index of about 1.62. This immersion method is useful for the determination of approximate index, but fails to provide the exact readings obtained on the refractometer.

B. W. Anderson pointed out that faceted stones lower in index than the liquid are easily distinguished from those of higher index by the appearance of the girdle and facet junctions. A flat-bottomed dish is placed over white paper and a liquid of known index is poured in. Gems are laid in the dish table down and a single lamp is placed over the tray. If the index of the gem is lower than that of the liquid, it casts a bright-edged shadow and facet junctions appear as black lines. If the stone is higher than the liquid in index, the shadow is dark edged and the facet edges appear as bright lines. The thickness of the bright or dark rim is a measure of the difference in index between liquid and stone. The rim may be colored, if the index or indices of the stone is or are almost identical to that of the liquid.

For this purpose, liquids of fairly high index and low density are ideal, so that even gems of low S.G. do not float. A floating gem has to be held down. Good liquids are monobromobenzene (1.56), monoiodobenzene (1.62), monobromonapthylene (1.66), and monoiodonapthylene (1.704).

By placing a photographic printing paper below the glass, photographs of results may be made.

The Becke Line. The most common mineralogical means of refractive index determination makes use of the Becke effect. The mineralogist powders samples of the unknown and places a drop of liquid of known refractive index over a small portion of the powder on a glass slide. The grains are examined under high magnification. When the light is transmitted through the liquid and grains of the unknown mineral, each grain appears to have light edges. When the tube of the microscope is raised, the bright edge (the so-called Becke line) moves toward the higher index. This is useful when a few grains of material can be taken from the rough, or scraped from the girdle of a cut stone. It is also useful to determine whether inclusions have higher or lower indices than the host gem material. Sets of refractive index liquids in steps of .01, from under 1.5 to over 1.8 are available.

Determination of Refractive Index with a Microscope. There are several methods of index determination possible with a microscope. By utilizing the calibrated fine adjustment of a good microscope, it is possible to determine the actual depth of the stone and then read the apparent depth by focusing through the stone.

To determine refractive index with a microscope: Place the stone on a slide on the microscope stage with the culet down. Focus the microscope on the table, which is nearest to the microscope objective in this position, and take a reading. Turn the focusing screw down (usually only the fine adjustment is calibrated, thus, the focusing must be done with this adjustment) until the instrument focuses on the culet of the gem, looking through the table; take a second reading. With the microscope focused on the glass slide on which the gem rests, take a third reading. The difference between the first and the last reading gives the true depth of the stone while the difference between the first two readings gives the apparent depth. These two figures are sufficient to determine the refractive index, since the refractive index is equal to the true depth divided by the apparent depth.

Microscopes that have no calibrated focusing adjustments can be adapted by attaching a Vernier millimeter scale along the side of the instrument. The millimeter scale should be placed on the fixed microscope stand, with the Vernier portion on the movable side. This method of refractive index determination is not accurate, but is useful for mounted stones on which no refractive reading can be taken, or with gems that have a refractive index too high to be read on the refractometer.

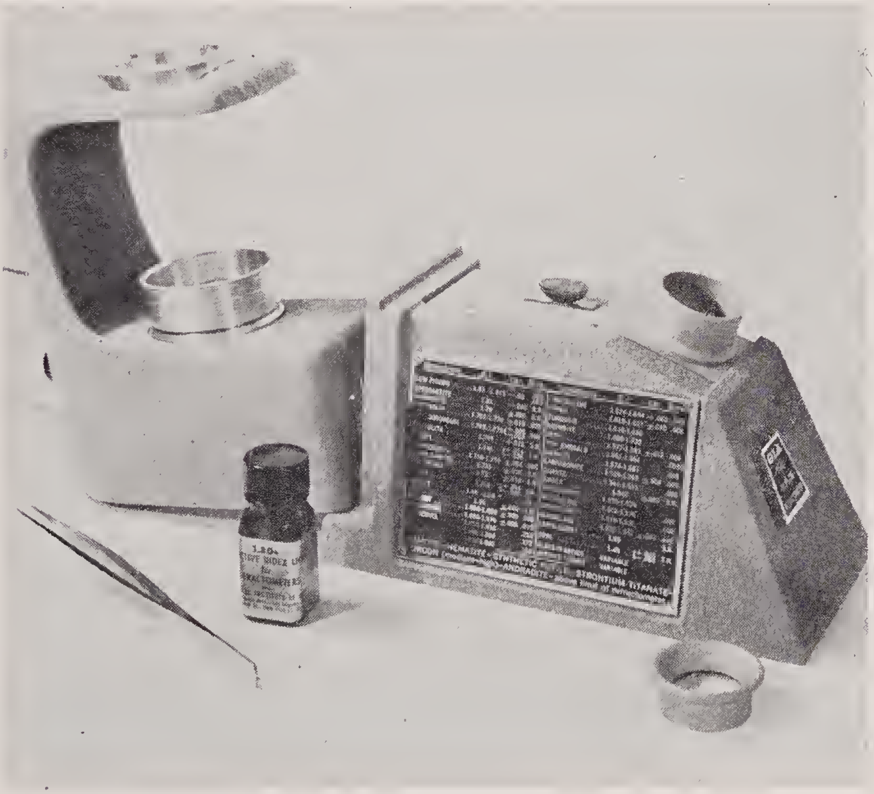

Figure 20

Duplex refractometer showing table of indices, and with auxiliary lens removed for spot reading

Refractive Index Table

Rutile & Syn	2.616		2.903
Anatase	2.493		2.554
Diamond		2.417	
Strontium titanate		2.409	
Stibiotantalite	2.37		2.45
Sphalerite		2.37	
Zincite	2.013		2.029
Cassiterite	1.997		2.093
Zircon (high)	1.925		1.984
Scheelite	1.918		1.934
Sphene	1.900(±.018)		2.034(±.020)
Zircon (medium)	1.875(±.045)		1.905(±.075)
Andradite garnet		1.875(±.020)	
Zircon (low)	1.810(±.020)		1.815(±.020)
Spessartite garnet		1.81(±.010)	
Almandite garnet		1.80(±.030)	
Gahnite		1.80	
Painite	1.787		1.816
Corundum	1.762(—.003,+.007)		1.770(—.003,+.008)
Synthetic corundum	1.762		1.770
Rhodolite garnet		1.76(±.010)	
Benitoite	1.757		1.804
Gahnospinel		1.76(±.02)	
Pyrope garnet		1.746(—.026,+.010)	
Chrysoberyl	1.746(±.004)		1.755(±.005)
Staurolite	1.736		1.746
Grossularite garnet		1.735(±.015)	
Azurite	1.73(±.010)		1.84(±.010)
Rhodonite	1.73		1.74
Epidote	1.729(—.015,+.006)		1.768(—.035,+.012)
Synthetic Spinel		1.73(±.01)	
Spinel		1.718(—.006,+.044)	
Taafeite	1.719		1.723
Kyanite	1.716(±.004)		1.731(±.004)
Idocrase	1.713(±.012)		1.718(±.014)
Zoisite	1.700		1.706
Willemite	1.69		1.72
Rhodizite		1.69	
Dumortierite	1.678		1.689
Axinite	1.678		1.688
Diopside	1.675(—.010,+.027)		1.701(—.007,+.029)
Sinhalite	1.668(±.003)		1.707(±.003)
Kornerupine	1.667(±.002)		1.680(±.003)
Malachite	1.66		1.91
Spodumene	1.660(±.005)		1.676(±.005)
Sillimanite	1.659		1.68
Jet		1.66(±.020)	
Enstatite	1.658(±.005)		1.668(±.005)
Dioptase	1.655(±.011)		1.708(±.012)
Jadeite	1.654		1.667
Euclase	1.654(±.004)		1.673(±.004)
Phenakite	1.654(—.003,+.017)		1.670(—.004,+.026)
Peridot	1.654(±.020)		1.690(±.020)
Apatite	1.642(.—012,+.003)		1.646(—.014,+.005)

Refractive Index Table

Andalusite	1.634(±.006)		1.643(±.004)
Danburite	1.630(±.003)		1.636(±.003)
Datolite	1.626		1.670
Tourmaline	1.624(±.005)		1.644(±.006)
Smithsonite	1.621		1.849
Topaz	1.619(±.010)		1.627(±.010)
Prehnite	1.615		1.646
Turquoise	1.61		1.65
Lazulite	1.612		1.643
Amblygonite	1.612		1.636
Bakelite		1.61(±.06)	
Nephrite	1.606		1.632
Brazilianite	1.602		1.621
Odontolite	1.60(±.03)		1.61(±.03)
Ekanite		1.597	
Rhodochrosite	1.597		1.817
Verdite		1.580	
Beryl	1.577(±.016)		1.583(±.017)
Synthetic emerald (Linde)	1.575		1.581
Augelite	1.574		1.588
Pseudophite	1.57		1.58
Synthetic emerald (Chatman)	1.561		1.565
Variscite	1.56		1.59
Coral (black)	1.56		1.57
Labradorite feldspar	1.559		1.568
Hambergite	1.555		1.625
Beryllonite	1.552		1.562
Agalmatolite	1.55		1.66
Scapolite	1.55		1.572
Quartz	1.544(±.00)		1.553(±.00)
Iolite	1.542(—.010, +.002)		1.551(—.011, +.045)
Steatite	1.54		1.590
Amber		1.540	
Chalcedony quartz	1.535		1.539
Apophyllite	1.535		1.537
Albite-oligoclase	1.532(±.007)		1.542(±.006)
Pollucite		1.525	
Microcline	1.522		1.530
Orthoclase	1.518		1.526
Thomsonite	1.515		1.540
Stichtite	1.516		1.542
Leucite		1.508	
Petalite	1.502		1.518
Lazurite (lapis-lazuli)		1.500	
Obsidian		1.500	
Lucite		1.495(±.005)	
Serpentine	1.56(—.07)		1.570(—.07)
Calcite	1.486		1.658
Coral	1.486		1.658
Sodalite		1.483(±.003)	
Moldavite		1.48	
Opal		1.45(—.080, +.020)	
Fluorite		1.434	
Glass (normal)		1.48 - 1.70	
(extreme)		1.44 - 1.77	

Chapter VI

Double Refraction, Pleochroism, and Optic Character

The Nature of Light. The exact nature of light is not fully understood. It is apparently emitted in infinitesimal particles called quanta, and is transmitted as an electromagnetic wave The wave motion of light may be likened in a crude way to the waves set up along a rope anchored at one end when it is snapped by sharp movements of the hand. The curve shown in Figure 21 illustrates the motion of light. The distance from A to A^1 or B to B^1 represents one wave length. The amplitude of the wave is the distance from C to C^1 or from D to D^1. The wave length of light is measured in Angstrom Units (one ten-millionth of a millimeter), or in millimicrons (one millionth of a millimeter).

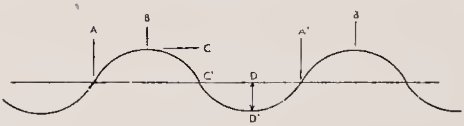

Figure 21
The wave motion of light.

When light is moving through air or any other gas, its waves may undulate or vibrate in any direction perpendicular to the direction of transmission. All liquids and some solids reduce the velocity of light from its velocity in air without offering restrictions other than partial absorption. Such liquids and solids are said to be *isotropic*, since the velocity of light is the same in all directions of transmission. All *amorphous* solids, such as opal and glass, and all materials which crystallize in the cubic system, are isotropic or singly refractive. Isotropic materials have but a single refractive index for any given wave length of light.

Solids which crystallize in the other five crystal systems have a more complicated effect upon light as it is transmitted through them. Light is forced to vibrate in two planes at right angles to each other, and the light vibrating in one of these directions is retarded in velocity more than the other; hence, such materials have two indices of refraction. As a result, a single ray of light which enters a gem crystallized in any but the cubic crystal system is broken into two rays. Each of the two rays, vibrating in a single plane, is said to be *plane polarized.* Solids which break light into two polarized beams as it is transmitted through them are said to be *anisotropic* or *doubly refractive.* The measure of the ability of a solid, such as a gem, to convert a single ray of light into two rays having unequal velocity is called BIREFRINGENCE. The numerical value for a gem's birefringence is obtained by subtracting the lowest refractive index from the highest given for that gem. A short table of birefringence of gemstones follows:

Birefringence Table

Apatite	.004	Kyanite	.016
BERYL	.006	Phenakite	.016
CORUNDUM	.008	Euclase	.019
TOPAZ	.008	TOURMALINE	.020
Andalusite	.009	Sillimanite	.021
CHRYSOBERYL	.009	PERIDOT	.038
QUARTZ	.009	ZIRCON	.059
Beryllonite	.010	Calcite	.172
SPODUMENE	.015	SYNTHETIC RUTILE	.287

Gems which crystallize in the hexagonal and tetragonal systems, such as sapphire, zircon, quartz and tourmaline, have one direction (*optic axis*) in which they fail to polarize light. Such doubly refractive or anisotropic materials with one direction of single refraction are said to be *uniaxial.*

Materials which crystallize in the orthorhombic, monoclinic, or triclinic crystal systems have two directions in which no polarization takes place (two singly refractive directions or *optic axes*). They are said to be *biaxial.*

The best illustration of the effect of double refraction is the appearance of a double image when any object is viewed through the transparent cleavage fragments of calcite (iceland spar), which has very strong birefringence (.17). Many gems show the same effect, but to a less marked degree.

Determination of Double Refraction Under Magnification. When zircon is examined through a loupe, the lines formed by the junction of facets appear as pairs of parallel lines when viewed through the stone, unless it is examined in the one direction of single refraction. If high magnification is used, doubling of the facet edges on the side of the gem away from the objective should be seen even in gems having very low birefringence, unless the direction of observation is parallel to an optic axis. Since doubly refractive gems have directions of single refraction, absence of doubling of facet junctions should not be interpreted as evidence of single refraction, unless the stone has been observed in more than two directions. In a direction of maximum birefringence, gems of carat size with a birefringence of .004 or more should show doubling under a magnification of 30 or more diameters. Inclusions within the gem often

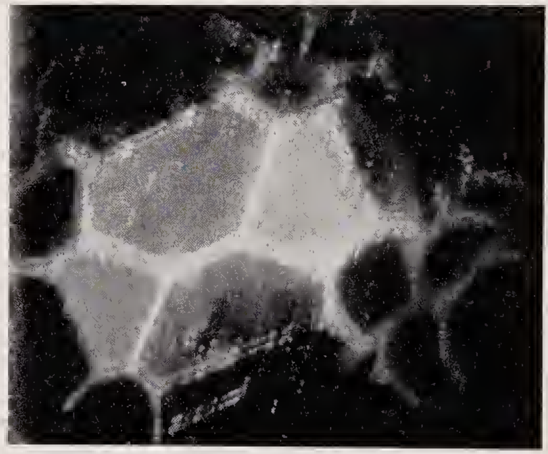

Photo by G.I.A.

Figure 22

Doubling of back facet edges in tourmaline under 10X magnification.

show the same doubling under magnification. While the absence of double images should not be interpreted as proof of single refraction, their presence is proof that the gem is doubly refractive.

Rotation of a Polaroid plate over the eyepiece will cause the two images caused by double refraction to appear individually and to seem to jump back and forth.

The Reflection Test for Double Refraction. A simple test for double refraction in transparent faceted gems which requires no instruments is the reflection test. Cut a hole one eighth to one fourth inch in diameter in a piece of white cardboard or stiff white paper. Hold the card so that sunlight or light from a powerful lamp passes through the hole and falls upon the crown of the gem. Light entering the crown will be reflected from the pavilion facets and refracted from the crown back to the lower side of the card to form a pattern of small dots. The dispersion of the gem often causes a pattern of rainbow spots. If the gem is doubly refractive, the spots will appear on the card in pairs

THE POLARISCOPE

Perhaps the simplest, yet one of the most valuable instruments

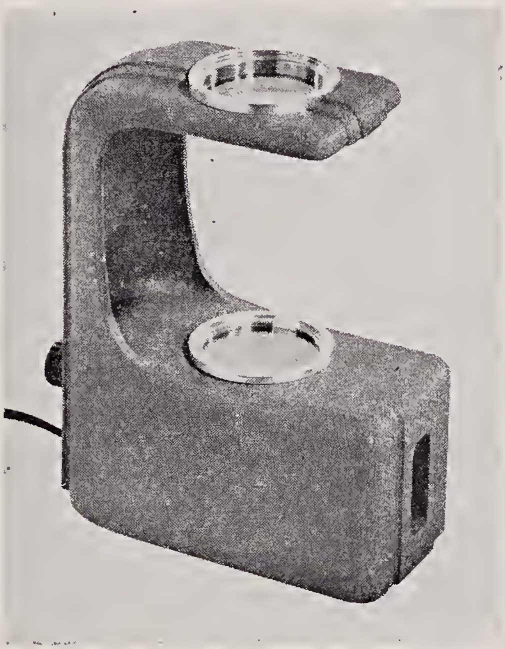

Figure 23

The Illuminator Polariscope

used in gem identification, is the polariscope. Although polariscopes had been used for more than a century, it was not until 1935 that one designed especially for gem testing, by Robert Shipley, Jr., was placed on the market. Since a polariscope is both efficient and inexpensive, it has become standard equipment in almost every American gem testing laboratory. The polariscope consists essentially of two Polaroid plates mounted a sufficient distance apart to permit gems to be examined between them. Usually, the lower Polaroid is fixed in position and the upper may be rotated.

The Illuminator Polariscope. The polariscope in widest use today is that known as the Illuminator Polariscope. This instrument has a single casting to mount a lamp and two Polaroid plates. The lamp is housed in the base, just beneath the lower Polaroid, or polarizer. The upper Polaroid plate (analyzer) may be rotated in a plane parallel to the polarizer. It is held between three and four inches above the polarizer on an arm extending over the lower plate. A light portal at the front of the instrument serves as a light source both for the refractometer and the dichroscope.

A stone to be examined in the polariscope may be held in stone tweezers, the tester's fingers, or in an immersion cup made to fit both the Illuminator Polariscope and the Gemolite. Perhaps the easiest and most convenient method is to use the fingers to manipulate the stone.

How to Use the Polariscope. All gem testing polariscopes are operated on the same principle. Gems are examined between crossed Polaroids; i.e., with the vibration direction of the analyzer turned at right angles to that of the polarizer. This is the dark, or extinction, position. When the upper Polaroid has been turned to the position of minimum light passage, examine the stone between the two plates. Since the light analyzed is that transmitted through the gem, only those with sufficient transparency to transmit light may be analyzed by this method. If the stone darkens and becomes light each 90° of rotation, double refraction is indicated. If it remains dark, it is singly refractive. In a doubly refractive stone the change varies from an abrupt light to darkness across the whole stone to one in which only a dark band moves across the transparent stone as it is

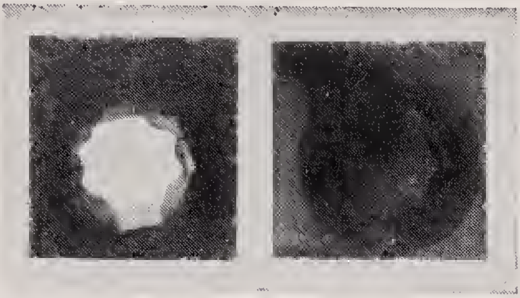

Figure 24

Behavior of a doubly refractive stone in the polariscope. At left, the gem is light; at right, a 45-degree turn of the cylinder twists the stone to its dark position.

rotated. The difference depends on the relationship of the tester's angle of view to the optic axis or axes of the stone. At right angles to an axis. the change is abrupt.

From right angles to an optic axis to from 75° to perhaps 45° (depending on the shape of the stone, whether it is faceted, its index level, whether uniaxial or biaxial and other factors) abrupt changes are usual. Closer to the optic axis direction. a band of dark moving across a usually light stone is to be expected. Within a few degrees of parallel to the optic axis, colors are usually visible in a doubly refractive stone. The significance of the colors is discussed in a later section in this chapter.

Cautions. Since double refractive gems have one or two directions of single refraction, it is necessary to examine them in more than two directions before assuming the gem to be singly refractive. Brilliant-cut gemstones should not be examined in a table-up or table-down position. because all light entering the crown may be totally reflected back in the same direction. Such stones should be examined through the girdle or a side of the crown and the opposite side of the pavilion.

The jeweler must watch for singly refractive materials which show a condition (caused by strain within the gem) called anomalous double refraction. which may be confused with true double refraction. Garnet, synthetic spinel. translucent opal, and glass are likely to exhibit this effect.

The Polariscope Test for Anomalous Double Refraction. Turn the upper Polaroid plate to the position in which minimum light transmission through the instrument is permitted. Rotate the stone between the plates. If the intensity of the light passing through the stone changes, turn the stone until it is in its brightest position.

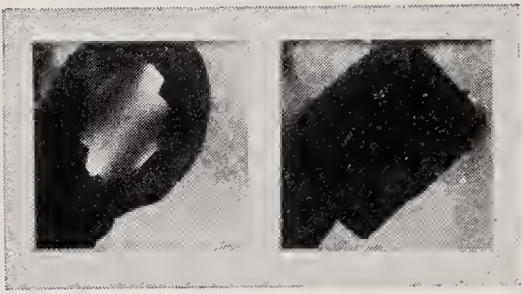

Figure 25

Left. Anomalous double refraction as seen in some glass imitations. Right. A singly refractive stone, which remains dark in all positions in the polariscope.

To determine whether the intensity change is caused by true or anomalous double refraction, turn the upper Polaroid until the polariscope allows maximum light transmission while holding the stone in a fixed position.

If the light coming through the stone increases as the upper Polaroid is rotated, anomalous double refraction in a singly refractive gemstone is indicated.

If the light coming through the stone either remains constant or decreases during the process, true double refraction is suggested. However, some red garnets react in this fashion. Since ruby, which they may resemble, is strongly dichroic, the dichroscope separates the two gemstones. The spectroscope serves the same purpose.

Doubly Refractive Crystalline Aggregates. Doubly refractive material such as jade, which is composed of numerous tiny crystals, causes a distinctive effect in the polariscope. When the two Polaroids are in the crossed, or dark, position, such gems will appear uniformly bright as the cylinder is rotated. Chalcedony and jade always react in this manner in the polariscope. The failure to extinguish in any position is a consequence of the random orientation of the multitude of tiny crystals which comprise the aggregate. In all positions of the stone a sufficient number of the small crystals are oriented in a direction in which light may pass, so that the gem will never darken. Some corundum also fails to extinguish in the polariscope. As a result of repeated twinning, certain sets of thin plates are in the dark (extinction) position while the alternate parallel plates are not; hence the gem appears light in all positions.

Translucent glass imitations may react similarly to doubly refractive aggregates in the polariscope, particularly if they have a rough back surface. In this event, tiny surface fractures displaying a vitreous luster distinguish glass from most crystalline aggregates used as gemstones. The polariscope reaction is not dependable for semitranslucent materials in which the only light transmitted is a minimum amount through thin edges. Under these conditions singly refractive materials often give results similar to those of doubly refractive aggregates.

PLEOCHROISM

Light which is transmitted through doubly refractive gems vibrates in two planes at right angles, with the two beams suffering unequal reduction in velocity. Traveling separate paths at different velocities, the two beams often suffer unequal absorption in colored anisotropic gemstones and emerge as different colors. This property is called PLEOCHROISM. Pleochroic gems in the hexagonal and tetragonal crystal systems show two different colors and are said to be *dichroic*.

DICHROISM is described as *strong, distinct, or weak.* Ruby, for example, shows very strong dichroism; emerald, distinct dichroism; citrine quartz, weak dichroism.

Pleochroic gems which crystallize in the orthorhombic, monoclinic, and triclinic systems may show three colors when viewed in various directions, but more often only two are easily distinguishable. Those in which three colors can be distinguished are said to be *trichroic.* TRICHROISM is described in the same manner as dichroism. Ruby, sapphire, emerald, and zircon are dichroic; the alexandrite variety of chrysoberyl is trichroic.

Pleochroism often can be seen without instruments, if the gem is examined from different directions. To see more than one color in any single direction, it is necessary to use optical instruments.

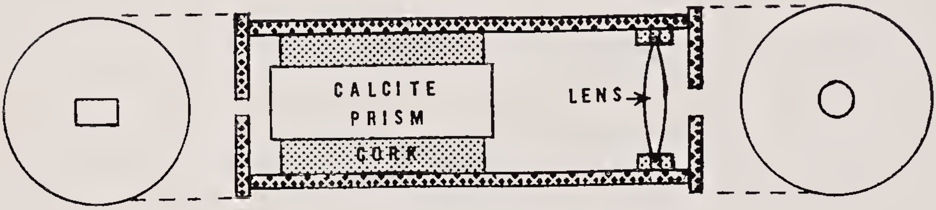

Figure 26
Dichroscope construction.

The Dichroscope. The dichroscope is a small instrument that employs the strong double refraction of colorless calcite to separate the two polarized rays of a dichroic gem. It consists of a tube with a square or rectangular aperture at one end, a cleavage piece of calcite with polished ends in the center, and a low power lens at the eyepiece. Dichroscopes are among the least expensive of gem-testing instruments. They are manufactured in this country and in England, and are available at the Gemological Institute of America, Los Angeles, for less than ten dollars.

Light, on entering the calcite, is broken into two polarized rays which have vibration directions at right angles to each other. These two rays are slowed unequally by the calcite so that one is bent (refracted) considerably more than the other. Two images of the square or rectangular aperture are visible through the dichroscope. The two images will have different colors when a pleochroic gem is examined through the instrument.

To Test a Gemstone for Pleochroism with the Dichroscope. The advantage of the dichroscope lies in the fact that the two pleochroic colors that may be characteristic of a given direction in a doubly refractive gem are seen side by side. A gem to be examined is held in stone tweezers or in the fingers about one-fourth to one-half inch from the rectangular opening. The lens at the eyepiece end of most dichroscopes focuses at about that distance from the square or rectangular window at the opposite end. As a light source, a microscope substage lamp is excellent. Any reasonably white incandescent light is satisfactory. Fluorescent lamps show a certain amount of polarization at the edges, so weak dichroism may be seen in a stone where none exists. Because of partially polarized reflection from facets and some polarization in light sources (even in the sky near the horizon), very, very weak dichroism should be regarded with suspicion.

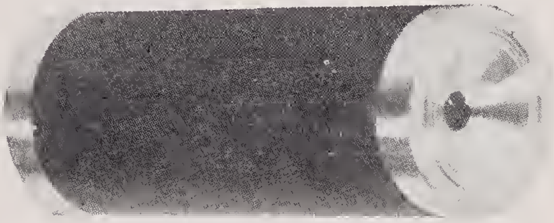

Figure 27
The G.I.A. Dichroscope.

If no dichroism is detected in the first direction examined, turn

Figure 28
Correct Use of the Dichroscope.

the stone and examine it in other directions. The two optic-axis directions in a biaxial pleochroic gemstone would show no difference in color in the two windows.

A gem which shows trichroism would display, for example, red and green in one direction, green and yellow in a second, and red and yellow in a third direction. Only two of the three trichroic colors could be seen in any one direction. Since pleochroic colors of a gem are often distinctive, the determination of pleochroism is valuable in gem identification. While many gems are doubly refractive, the number which show strong dichroism is small. Tables indicating the characteristic dichroic colors of various gems are included in each of the identification chapters. Unless the dichroism exhibited is unlike that for any but a single gemstone, it is best to consider it proof of double refraction only, and not of the stone's identity.

The direction in which dichroism can be seen is also important because it gives an indication of the synthetic or genuine origin of corundum. Almost all genuine corundum is cut so that the table is at right angles to the optic axis, while most synthetic gems are cut so that the table of the cut stone is usually more or less parallel to the optic axis. As a result, natural ruby and sapphire seldom show dichroism when viewed through the table, whereas their synthetic counterparts show strong dichroism through the table.

Use of the Polariscope in Detecting Pleochroism. The polariscope detects pleochroism effectively when the analyzer is turned to the parallel position, allowing maximum transmission of light. When held between the polarizer and analyzer, a pleochroic stone will show different colors in positions 90 degrees apart, as it is rotated. The polariscope is a less satisfactory instrument for the determination of pleochroism than is the dichroscope, because the two colors are not seen simultaneously as they are in the latter. Nevertheless, there are gemologists who feel that the polariscope offers a more effective means for detecting pleochroism in very light stones in which no color difference can be detected with a dichroscope.

OPTIC CHARACTER

The determination of the uniaxial or biaxial character of a doubly refractive gemstone often provides an important clue to its identity.

Uniaxial gems have two refractive indices, one of which is constant for any direction. The other index varies from the constant index to a point above or below it. If the constant index is the lower numerically, the material is said to be positive. If the upper index is constant, and the lower is variable, the stone is said to be negative.

Optically *biaxial* gemstones are also either positive or negative, but since they have three refractive indices (only the highest and lowest are given in most refractive index tables), the signs are determined in a different manner. The highest and lowest indices vary from their maximum and minimum positions to the intermediate (beta) index. If the numerically highest index (gamma) is closer to the intermediate one than is the lowest index (alpha), the gem is said to be negative. If the lowest is closer to the intermediate (beta) index, the gem is said to be positive. A test of this kind might seem to be out of place in a text of this nature, but the determination is not difficult with the refractometer.

Determination of Optic Character on the Refractometer. If a gemstone has a large birefringence (.015 or more), or if a monochromatic light source is used, it is often possible to determine the optic character. If, as the gemstone is rotated, one refractive index reading remains the same while the other varies, the gemstone is uniaxial. If the lower index is the one that does not vary, the gem is uniaxial with a positive optic sign. If the higher index is constant but the lower index varies, the optical sign is negative. For example, corundum has indices of 1.762 and 1.770, of which the higher reading 1.770 is constant, while the former varies from 1.762 to 1.770. Since the higher is constant, corundum is negative in sign. The birefringence of the gem is represented by the maximum difference between the two indices.

Biaxial gems are distinguished on the refractometer by a variation of both the upper and lower indices as the hemisphere is rotated. The same effect is noted on a refractometer with a fixed dense glass hemisphere or prism by rotating the gem instead of the hemisphere. As the biaxial gem is rotated, both the high and low indices vary; the high from an intermediate point up to a maximum reading, and the low from a minimum reading up to the same intermediate position. The optical sign of the biaxial gem may be determined by noting whether the minimum or maximum reading is farthest from the intermediate position from which both vary. If the numerically higher reading is closer to the intermediate index than is the lower, the gem is said to be optically negative. If the lower index is closer to the intermediate index, the gem is said to be optically positive. For example, if readings were taken on topaz and the low reading varied from 1.629 to 1.631 and the high reading from 1.637 down to 1.631, 1.631 would be the intermediate index and the optic sign positive because 1.629, the lowest reading, is closer to the intermediate reading. In some cases, minimum position of the high reading and the maximum position of the low will either overlap or fail to reach a reading common to both. In this event, approximate the position of the intermediate index by taking a figure midway between the two. It should be noted that there are two possible orientations in biaxial stones in which one index remains constant during rotation on a facet and the other index does not reach it. A reading on a second facet should disclose the gem's biaxial nature.

Analyzing Refractometer. In 1949, Robert Shipley, Jr., and Noel Alton introduced two refractometers employing polarizing systems to analyze the nature of the birefringence of gemstones. One utilizes white light and filters and the other monochromatic (sodium) light. One Polaroid film with its vibration directio at 45° or 90° to the contact surface of the hemisphere, is placed between the light source and the refractometer light portal, and a second over the eyepiece at 90° to the first. With this arrangement of Polaroid, the portion of the scale between the high and low readings for a doubly refractive gemstone appears light and the remainder of the scale dark. As the stone is rotated on the hemisphere, the changes in width and position of the birefringent bar of light are analyzed in the manner outlined in the preceding paragraphs.

Singly refractive materials without strain double refraction show no light bar when the Polaroids are in a crossed position. Strained singly refractive materials display a light line without measurable width. These instruments are useful particularly for unusual gemstones, rarely encountered by the jeweler.

Figure 29

Rotating a Polaroid Plate in front of the eyepiece to detect birefringence on a spot reading

The Use of the Polariscope in the Determination of Optic Character. There are several tests that may be performed with instruments used primarily for other purposes that will materially assist in an occasional difficult identification. One of the most valuable is the determination of optic character with the polariscope.

If a doubly refractive gem is examined through the polariscope in a direction parallel to an optic axis, an interference figure will be seen under certain conditions. Figures 31 and 32 illustrate uniaxial and biaxial figures observed in this way. Three conditions must be observed to obtain an interference figure in the polariscope: (1) the gem must be mounted so that an optic axis is perpendicular to the Polaroid plate (parallel to the length of the cylinder); (2) the analyzer (upper Polaroid plate) must be turned to the extinction (dark) position; (3) a condensing lens effect must be obtained.

The second condition is easily met, but the first and third are more difficult. Since the majority of uniaxial gems are cut with the table more or less perpendicular to the optic axis, mount or hold the stone so that the table is parallel to the analyzer. The observer is able to recognize the correct orientation by the appearance of bright colors within the gem. If the optic axis is perpendicular to the Polaroid plates, there should be a minimum light intensity change as the cylinder is rotated. If the first position in which the gem is held does not seem to be parallel to the optic axis, turn the gem while observing it. As the stone is rotated, a dark line may be observed. Turn the stone in the direction which causes the dark line to become more sharply defined. As the line appears sharper and narrower, interference colors should appear.

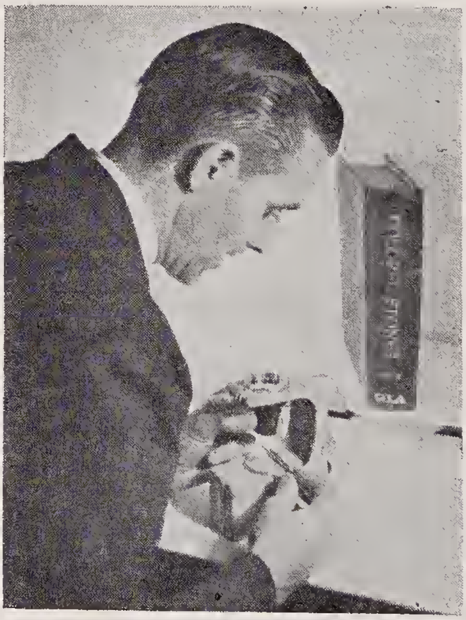

Figure 30
A 10X loupe held under the top piece of the polariscope resolves the interference figure

The third condition may be difficult to meet in a faceted gem, but gems cut *en cabochon* act as condensing lenses. Therefore, interference figures are usually resolved in such gems in determining the singly or doubly refractive character. Two principal methods of producing the condensing lens effect are available with faceted gems. A simple method involves the placing of a drop of viscous liquid on the gem after it has been oriented properly.

A 10X loupe held under the top piece of the polariscope resolves the interference figure when viewed from a distance of eighteen inches or more. Immersion of the gemstone in a small beaker or the bottom section cut from a test tube filled with water or bromoform often permits resolution of an interference figure difficult to obtain otherwise.

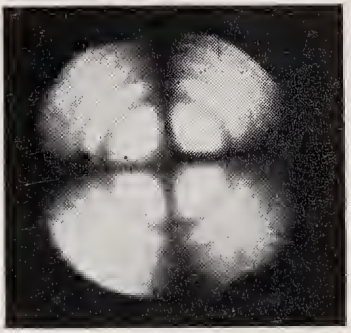

Figure 31

A uniaxial interference figure.

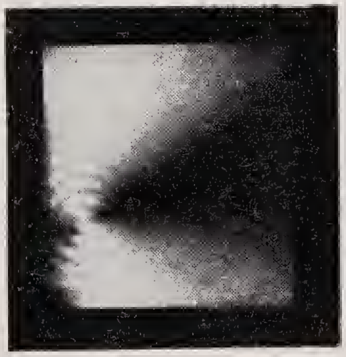

Figure 32

A biaxial interference figure parallel to an optic axis.

The Moore Sphere. A more effective means of condensing light to produce interference figures is provided by a liquid-filled glass sphere at the center of which a gemstone is mounted. Such an immersion vessel is the Moore Sphere pictured in Figure 33. By placing this small instrument between crossed Polaroid plates, it is possible usually to resolve an interference figure in a matter of a few seconds by rotating the sphere in a direction in which the dark line or brush becomes sharper and narrower. When interference colors appear, a 10X loupe placed above the sphere and observed from a distance of 18 inches or more should resolve the interference figure.

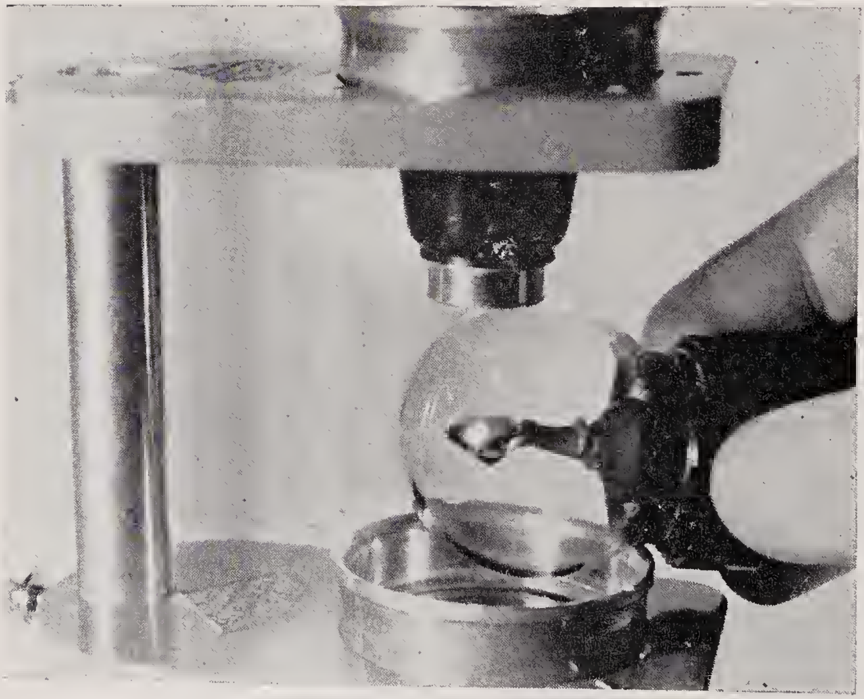

Figure 33

The Moore Sphere held between the Polaroid plates of a Gem Polariscope. A low powered loupe rests under the analyzer.

The distinction between uniaxial and biaxial gems has many uses. It is the easiest way to distinguish between precious moonstone (orthoclase) and the chalcedonic quartz variety, since both are normally cut *en cabochon* and no condensing lens is necessary to resolve the interference figure in precious moonstone. Since chalcedony is composed of a multitude of tiny crystals, no figure can be obtained. Similar determinations also serve to distinguish between topaz and tourmaline, and between corundum and chrysoberyl. The addition of a quartz wedge to the tester's equipment materially increases the value of interference figures, since the optic sign (positive or negative) can be determined with the wedge.

The beginner will find difficulty in obtaining interference figures with the polariscope, except when gems are cut *en cabochon.* However, the test becomes so valuable in difficult identifications that it is wise to develop the necessary technique.

Chapter VII

Magnification

Importance to Gem Identification. A vitally important factor in the correct identification of gems is the proper use of magnification, since clear resolution of inclusions is essential to distinguish man-made substitutes from natural gemstones. Almost every jeweler has become proficient in the use of the eye loupe to seek out imperfections in diamond. The care that is used to grade diamonds, however, is seldom carried over into the examination of colored gems, even though the imperfections or inclusions may mean a greater value differentiation than is true in the case of diamond. The difference lies not in a reduction of value because of the presence of flaws, but in the proof of artificial or natural origin established by flaws. Many jewelers will base an identification on a hasty examination of a gem that may be genuine ruby or synthetic ruby with a difference in value of thousands of dollars. The same jewelers will spend ten minutes or more grading a diamond for flawlessness, although the flawless stone may be worth only $50 more than the slightly imperfect stone. Obviously, then, the examination of colored gems demands the careful attention of the jeweler. There are several means of magnification the gem tester can utilize in his laboratory.

MAGNIFYING INSTRUMENTS

Numerous types of loupes and microscopes are used for gem identification. The magnification range is from two to over six hundred diameters. Under the loupe and under the microscope, efficient lighting of the gem is essential to successful magnification. Inasmuch as a transparent gemstone is usually cut for maximum brilliancy, the reflection of light from its many facets adds materially to the examiner's difficulties. The lighting problem increases with increasing magnification; in fact, magnifications of 200 diameters or more are rarely useful in gem identification. It is apparent that the magnifier chosen by the gem tester must be one which has an efficient light source or one that may be so adapted that efficient lighting is easily obtained. Dark-field illumination, in which light is directed into the gem from the side, usually provides the most effective method of illuminating the interior of a gemstone. (See Figure 34.)

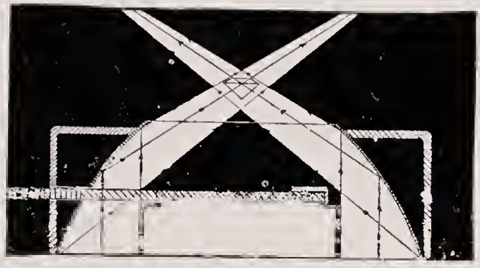

Figure 34
Diagram of a dark-field illuminator.

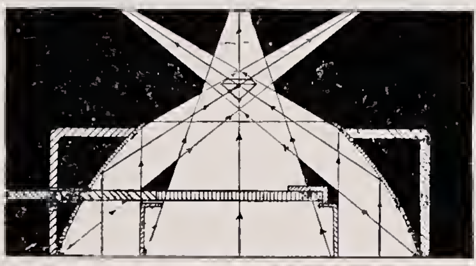

Figure 35
Diagram of a direct illuminator.

Loupes. Lenses of many diameters and various magnifications are used in jewelers' loupes. The best of these are triplets, corrected for chromatic and spherical aberration. The correction, both practical and necessary, places the entire field in focus at once and eliminates the confusing color fringe visible around magnified objects seen through an uncorrected loupe. (See Chapter X on distinction between synthetic and genuine gems.) The wider the field of the ten power corrected loupe, the more light it transmits to the eye, increasing its usefulness. If a loupe of ten power or higher magnification is not corrected, the field, partially masked, is small.

A loupe of less than ten power will seldom resolve inclusions well enough for the observer to determine their nature. A loupe of greater than ten power has so short a focal distance that adequate lighting is achieved with difficulty and observation becomes more complicated.

Figure 36
The G.I.A. 10x Loupes.

Only in a minority of examinations will skilled use of the best of loupes provide satisfactory magnification for distinction between genuine and artificial or synthetic gemstones. For the majority of identifications, the higher magnification provided by the microscope is essential.

Microscopes. Microscopes are manufactured for a wide variety of specialized scientific and industrial purposes. Many types may be adapted for fairly efficient magnification of gems. Medical and biological stands, both monocular and binocular, prove very useful in gem tests. The type of binocular microscope adapted for gem use by the Gemological Institute of America has many advantages over the usual monocular microscope and other types of binocular. The combination of objectives of low power with wide-field eyepieces yields an especially wide field of vision, covering a much greater-than-usual area at any given magnification. The stereoscopic vision permits objects to be located exactly and their nature to be identified. The highly effective dark-field illumination provides the needed contrast for the efficient examination of the surface and interior characteristics of gemstones. All of the instruments herein described utilize a spring-loaded stone holder, opening to a full twenty-five millimeters to hold rings, and other larger jewelry pieces, as well as loose stones.

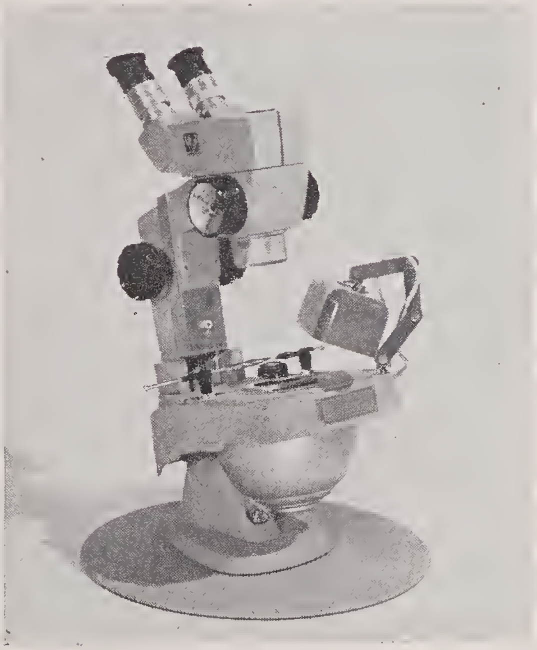

Figure 37
The Diamondscope.

The Diamondscope. The Diamondscope employs a binocular microscope mounted on a base containing a built-in illuminator designed for gemstone examination. This instrument has adjustable paired 15X wide-field eyepieces which are used in conjunction with paired .67, 1.33 and 2.67X objectives. The latter.

set in a drum nosepiece, may be thrown alternately into line with the eyepieces by a turn of the wrist to give magnifications of 10, 20 and 40X. Magnifications as high as 80X may be obtained with an adaptor lens. The Diamondscope's objectives are designed to be approximately parfocal; i.e., the instrument remains nearly in focus when the objective is changed.

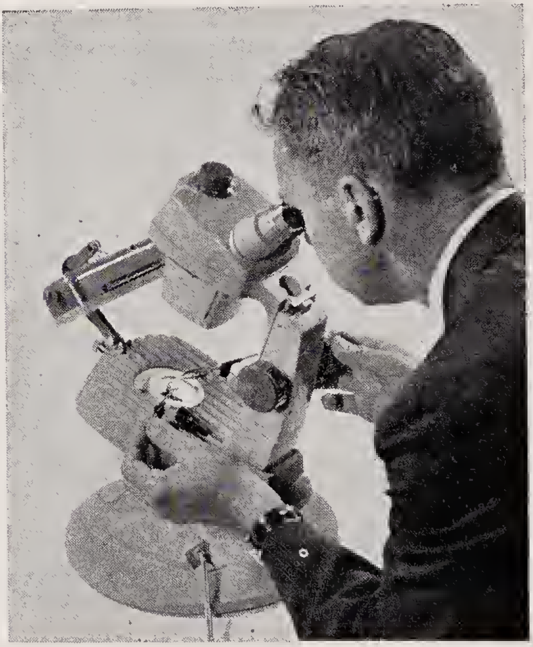

Figure 38

Examining a gemstone on the Mark V Gemolite

A mechanical stone holder (Figure 37) which may be mounted on either side of the illuminator base, is furnished to hold either mounted or loose gems. The illuminator base has an interchangeable background for dark-field and direct illumination of a gem.

With its many features designed for the most efficient examination of gems, the Diamondscope is perhaps the most practical gem microscope. However, the name Diamondscope is a trademark name controlled by the American Gem Society, which does not sell, but only leases the instrument subject to rulings governing its use in business.

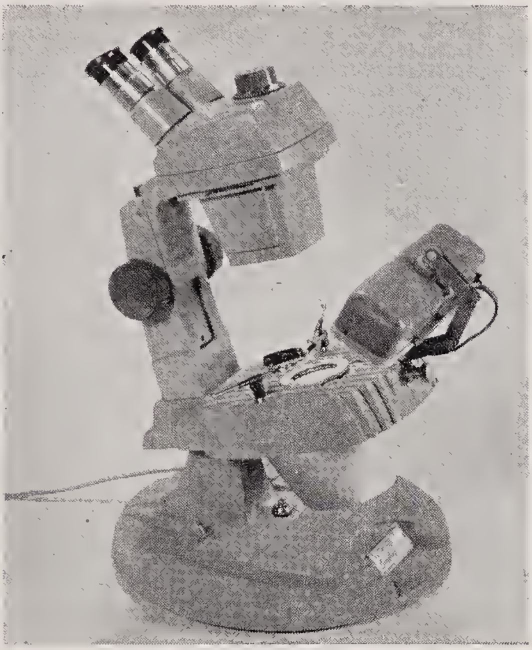

Figure 39

The Mark V Gemolite

The Gemolite. Since 1948, the Gemolite has been available to the jeweler and gemtester for gem identification and quality grading. This instrument employs a wide-field binocular microscope mounted on a base designed for highly efficient illumination of transparent gemstones. An overhead light source is used to illuminate opaque stones. The gem or jewelry is held in a mechanical spring-loaded stone holder that offers easy manipulation and almost universal motion. An iris diaphragm serves a variety of purposes for controlling the light on the stone. Earlier models employed .7, 2 and 4X objectives, with 15X wide-field eyepieces, to yield magnifications of 10.5, 30 and 60X. The present model has the Stereozoom feature, offering an infinite number of magnifications between 10 and 45X with 15X eyepieces. The field at 10X is an inch, and at

45X, one-quarter inch or nearly the diameter of a one-carat round diamond brilliant. A 2X adapter doubles the magnification range to 20 to 90X. The Gemolite has a rotating base and a tilting mechanism for convenience.

The Gem Detector. A smaller, inexpensive binocular microscope of Japanese manufacture mounted on an American dark-field illuminator provides an alternative source of magnification for gem examination. Usual models offer magnifications of from 10 to 30X. The same stone holder used on the Gemolite is mounted on a post on the stage of the Gem Detector. Although it is equipped to give only dark-field illumination, light field is easily obtained by placing a sheet of white paper, plastic, or frosted glass over the light portal in the stage.

Other Microscopes. For gem identification the loupe is often inadequate. To obtain greater magnification at a lower cost than that called for by a Gemolite or Diamondscope, the tester may then turn to a Gem Detector or to a monocular microscope. Monocular microscopes are available in a price range of about that of a good loupe up to about triple the cost of a Gemolite (for a petrographie microscope with attachments). Inexpensive student medical and biological stands usually are designed for the study of slides at high magnification and are useless for gem work. However, if student microscopes can be obtained with 10X or 15X wide-field oculars and 1X and 4X objectives, they are useful, if a satisfactory form of dark-field illumination can be improvised. Among monocular microscopes, one that gives erect images is particularly desirable.

PROCEDURE FOR THE EXAMINATION OF GEMS UNDER MAGNIFICATION

Since examination procedures vary according to the types of magnification described in the preceding paragraphs, the use of each type will be described separately. A certain portion of the procedure for gem examination under magnification is necessary whatever the type of magnification employed.

Cleaning the Gemstone. All stones must be carefully cleaned before they are examined. The most confusing aspect of the classification of gemstone inclusions under magnification is the presence of surface dust which may easily be mistaken for internal inclusions. The possibility for costly interpretative errors emphasizes the need for exceptional care in cleaning a gem. Many cleaning methods may be used effectively, but some are more efficient than others. Probably the best cleaning method is that in which the gem is dipped into carbon tetrachloride, acetone, alcohol, or some similar solvent, and then wiped carefully in a piece of red silk. Silk is preferable to cotton or other

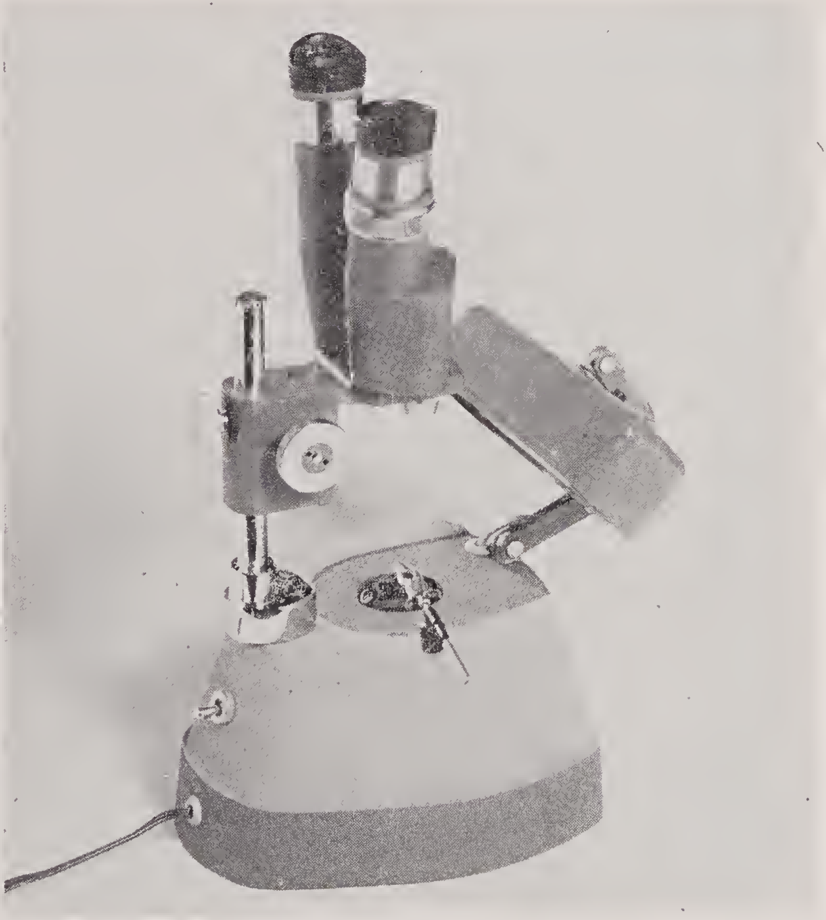

Figure 40

The Gem Detector

cloth, since it is less likely to leave lint on the stone. While any color would suffice, a brightly colored silk cloth is best since its threads are not likely to be confused with internal imperfections. In the absence of a solvent, careful rubbing with a silk cloth may render the gem sufficiently clean to avoid confusion. Paper facial tissues are satisfactory for cleaning loose stones. Since lint is sure to remain after tissue use. blowing on the stone is essential to remove most adhering particles. The carefully cleaned stone should be mounted without being touched by the fingers. A small camel's hair brush is a helpful accessory to flick off any surface dust that remains after the stone has been mounted. The major difficulty encountered by the novice in microscopic examination of gemstones (the confusion of surface dust with internal imperfections) will be rendered negligible if the gem has been carefully cleaned.

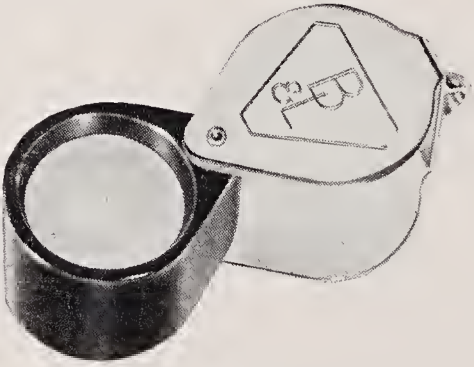

Figure 41

A 10X triplet hand loupe

The Use of the Loupe. The brilliant-cut gemstone must be as carefully lighted for loupe examination as for examination under higher magnification. Carefully clean the stone to remove dust, pick it up with stone tweezers, and hold over a black background. With a small lamp, direct light into the gem from the side. Imperfections within the gem will appear as bright objects clearly visible against a black background. The dark-field illumination described improves visibility of inclusions under all the many types of jewelers' loupes.

The Use of Microscopes. Mounting the Stone in a Mechanical Holder. If the gemstone is to be examined under the Gemolite. Diamondscope. Gem Detector or the gemological microscope. remove it from the silk cloth or facial tissue with the mechanical stone holder without touching it with the fingers. For best results, place the gem, table down, on the silk and grasp it at the girdle. Mount the stone holder on its post on the instrument, and turn it so that the stone can be examined with the table facing the microscope objective.

Mounting the Stone on a Glass Slide. If a microscope without a mechanical stone holder is used, the gem is usually mounted on a glass slide. A small piece of beeswax, plasticine or other material that can be shaped easily, is used to hold the stone. To mount the stone, hold it in tweezers to avoid touching it with the fingers and apply wax to the girdle. By means of the wax, transfer the stone to a small glass microscope slide and place the slide on the stage of the microscope. For best results, mount the stone with the table parallel to the slide and with the culet resting on the slide. The gem may be placed table down on a glass slide without using wax if the microscope is in a vertical position, but it is more difficult to see inclusions clearly from this direction, whereas mounting with wax takes little time and places the stone in a position especially advantageous for examining the interior.

Lighting. If the microscope has a built-in illuminator. close the baffle to give dark-field lighting and adjust the stone so that it is well lighted. If an ordinary microscope is used. direct the light toward the stone from the side at the level of the stage. Adjust it so the interior of the stone is well lighted. but with a minimum of bright reflections into the microscope.

Focusing. The working distance for binocular gem-testing microscopes is such that the gem is several inches from the objective.

Focusing is usually accomplished first with the lowest magnification. Additional magnification is then employed as needed. With a monocular, such as the gemological microscope, the process is more exacting. First make certain that the microscope has its lowest power objective in position, then use the coarse adjustment knob to turn the body tube down so that the objective comes close to the stone.

> **Caution:** To avoid damage to either objective or gem caused by lowering the objective until it strikes the stone, adjust the body tube downward, while observing the objective from the side of the instrument, until it nearly touches the stone.

The light used with either an ordinary or a polarizing microscope should be approximately adjusted to a position which permits a maximum illumination of the gem before a focus is attempted.

Bring the gem into focus by raising the body tube with the coarse adjustment knob while looking through the instrument. When the gem has been resolved under low power, adjust the light more carefully for maximum illumination of the stone's interior. If the microscope does not have an illuminator base, improve resolution of the gem's interior by holding a small substage lamp beside the stage of the instrument.

As the gem comes into focus, the culet will appear first; then, as the tube is raised farther, the table will appear. If the focus is changed *very slowly* from culet to table, any inclusions within the gem will come into and out of focus as the tube is raised to a focus on the table. When this focus change is made on a polarizing microscope, use the fine adjustment knob.

Distinction Between Dust and Inclusions. Surface dust, easily mistaken for internal imperfections in a gem, constitutes a confusing element for the beginner in gemstone identification. Even an experienced microscopist occasionally encounters difficulty because of dust. Since the most careful cleaning will seldom remove all surface dust, the observer must become adept at distinguishing correctly between dust and inclusions.

If the objects in question are exactly in focus when the table is in focus, it will not be difficult to determine that they are on the surface. If there is any doubt, touch the table of the gem with a camel's hair brush to see if the supposed imperfections disappear.

Dust on pavilion facets is especially confusing. When the focus is raised from the culet to the table, pavilion facets come into focus from the bottom to the top; thus, surface dust and true inclusions come into resolution at the same time. If the stone is mounted, and therefore difficult to dust with a camel's hair brush, it is often possible to remove dust from pavilion facets by blowing sharply against the gem.

To best determine whether an object apparently resting on a pavilion facet is surface dust or an internal imperfection, observe the facet junctions very carefully. Where the facets meet along the back of the gem, only the portions in the plane of focus will be seen clearly. If the object in question is between adjoining facet junctions, it is probably on the surface. If the object in the center of the stone, or at some distance from any surface which

Figure 42

Pavilion view of a single included crystal.

Figure 43

Table view of the same inclusion, which appears as eight inclusions by reflection.

is in focus when the inclusion is most clearly visible, it must be within the stone. A mechanical stone holder is helpful in this determination because in it the gem may be easily turned for better perspective and its pavilion facets may be more readily cleaned with the camel's hair brush.

Higher Magnification. Examination of the gem under lowest magnification will usually disclose internal imperfections in most colored gems, whether synthetic or genuine. Often, however, although imperfections are discovered, higher magnification is necessary to catalogue them correctly. With higher magnifications it is essential to increase the light sufficiently to bring the inclusions into clear resolution. When magnification is over one hundred diameters, a very brilliant light is essential to light the interior of the stone sufficiently to see inclusions clearly. Sharpness of definition decreases with increase in magnification. This, together with the lack of sufficient light, places a very definite upper limit on the use of higher magnification.

Immersion. Lighting the interior of a gem for most efficient examination under higher magnification is complicated by the reflection from the polished facets. Gems are faceted to take full advantage of their ability to bend light which enters them. Since the quality of brilliance requires that the gem return to the eye as much as possible of the light that enters the top of the stone, normal lighting of the microscope stage is insufficient for an examination under higher magnification.

The confusing effect due to reflections from the facets may be avoided by immersing the gem in a liquid whose refractive power is close to that of the gem. If a gem is suspended in a liquid that has a refractive index equal to its own, it becomes practically invisible; the facets are no longer a cause of distortion, and lighting becomes a much simpler problem. It is not necessary for the liquid to be close in index to the gem under examination. Any liquid, such as water or mineral oil, is helpful, but with gems of high refractive index a liquid with an index higher than that of water will give best results.

The following are suggested as suitable immersion liquids:

Liquid	Refractive Index
Water	1.34
Olive Oil	1.47
Benzol	1.50
Clove Oil	1.53
Momobromobenzene	1.56
Bromoform	1.59
Monoiodobenzene	1.62
Monobromonapthylene	1.66
Methylene Iodide	1.74

The Immersion Cell. The method of using an immersion liquid will vary depending upon the equipment. Immersion cells, valuable accessory equipment for the microscope or loupe, increase the value of these instruments, since they become more efficient magnifiers when the gemstone is immersed.

The use of an immersion cell has many advantages: (1) the observer experiences much less difficulty in seeing into a highly reflective gem; (2) light penetrates the gem, thoroughly illuminating inclusions; (3) the distinction between surface and internal imperfections is facilitated; and (4) growth lines become much more evident.

If the jeweler has no manufactured immersion cell, an excellent one may be improvised by using a small glass beaker, or even a very small drinking glass, with a fairly clear bottom and sides which allow light to enter the liquid. The gem to be examined may be placed in the bottom of the immersion cell, held in the liquid by means of tweezers, or held in wax attached to a rod of any type. For convenient manipulation of the stone, if held in tweezers or on the end of a rod, the sides of the immersion cell must be low; preferably about an inch high.

Another type of immersion cell is easily made by cutting off the bottom of a glass test tube of fairly small diameter. Little liquid is required to fill the small hemisphere that remains, and the gem can be supported on the bottom of the curve without the aid of a stone holder. A cylinderical section of a test tube cemented to a glass slide also makes an effective immersion cell. To resolve curved striae or angular growth lines, an opal-glass container, such as a cold-cream jar, is excellent.

Determinations Facilitated by Immersion. Assembled Stones. Immersion is an excellent means for quick and positive identification of assembled stones. In DOUBLETS OR TRIPLETS the separation planes are easily seen either as planes of bubbles or as divisions between two distinct colors. In GARNET-and-GLASS DOUBLETS, the genuine inclusions in the garnet cap are seen, as well as the bubbles that appear where the glass back has been fused to the garnet. In addition, the difference in luster and transparency of the garnet and the glass are readily seen.

Figure 44

A Gemolite immersion cell (foreground) and three satisfactory substitutes

Natural or Synthetic Origin. To find corundum and synthetic corundum to be almost entirely without visible flaw is not uncommon. If it is not possible to determine the natural or man-made origin of a ruby or sapphire by observation in air, immersion is the only alternative. Since it is possible to examine the interior of an immersed stone with increased efficiency, the examiner often finds hitherto unseen imperfections that provide the necessary evidence for a decision as to the synthetic or natural character of spinel or corundum. If however, no inclusions are resolved, he must seek out growth lines.

Immersion in a liquid such as bromoform and a careful control of the light source provide effective conditions for growth line resolution. Light must be reduced to a pin-point source either by an iris diaphragm below the immersion cell, or by an opaque cover with a small opening over the light source. The light source should be directly below the stone in line with the microscope. With practice curved striae in synthetic corundum and the straight zoning of natural ruby and sapphire can be resolved almost without exception.

Double Refraction and Birefringence. Even weak birefringence or double refraction is evidenced by the appearance of a doubling of the back facets of an immersed gem. The junction line between two facets will appear to be doubled and will show as two parallel lines where only one actually exists. Gems of high birefringence such as zircon (.059), peridot (.038), benitoite (.047). and tourmaline (.020) show this phenomenon even in tiny stones. If large gems (two or more carats) are examined, even materials with weak birefringence, such as topaz (.008) and beryl (.006) will show doubling of the back facets when examined in direction of maximum birefringence.

The same doubling of images applies to inclusions. Small inclusions in corundum and synthetic corundum often show this effect, rendering it difficult to distinguish the shape of the objects.

Doubling of back facets and inclusions is, of course, proof of double refraction. By the amount of doubling, the examiner can estimate roughly the birefringence of the gem. By examining a zircon, a peridot, a tourmaline and a sapphire of about the same depth, the microscopist can get an idea of relative birefringence that will enable him to judge an unknown fairly accurately. It is important to remember that there is no birefringence parallel to an optic axis, so relative birefringence should be judged after an examination in a direction of maximum doubling.

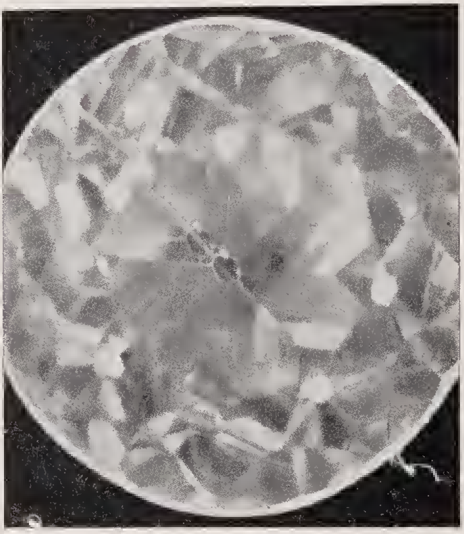

Photo by G.I.A.

Figure 45

Doubling of back facet edges in synthetic rutile under 10X *magnification.*

Chapter VIII

The Use of Characteristic Imperfections as a Means of Gem Identification

The tests commonly used in gemstone identification are based upon definite, tangible instrument determinations: the refractometer and specific gravity tests give definite numerical results, the dichroscope may show distinct colors, and polariscope determinations are clear-cut. Employing prescribed instruments and established methods, a jeweler, after sufficient practice, can become skillful in securing satisfactory results with these instruments and methods.

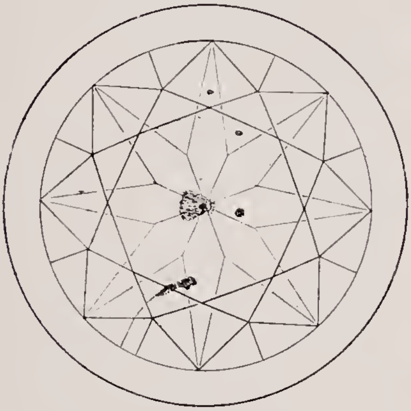

Figure 46

The appearance of a gem under magnification in ordinary illumination.

Figure 47

The same gem lighted by a dark-field illuminator such as that of the Gemolite.

By comparison, proficiency in identification of gemstones by means of their characteristic inclusions or imperfections involves a knowledge not quickly obtained by reading the printed page. To acquire skill in this method of identification, the jeweler must be thoroughly familiar with the subject of magnification; he must have a keen eye for accurate classification of inclusions or imperfections which involve, at times, the most fanciful shapes. Much more experience in the observation of gemstones will be required to achieve skill in this method.

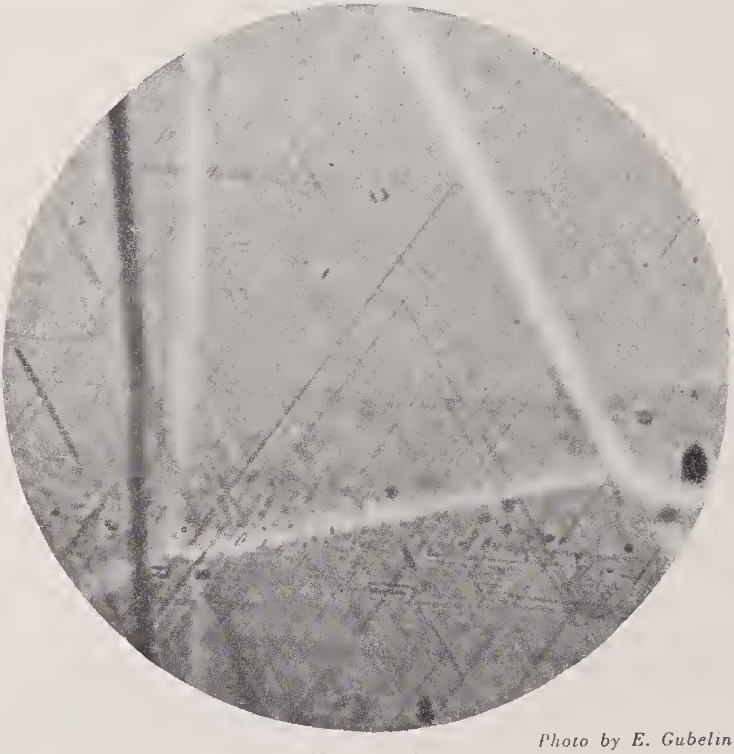

Photo by E. Gubelin

Figure 48

"Silk" consisting of three sets of rutile needles arranged at 60 degrees to each other in natural corundum.

Each time a jeweler makes a positive identification by the standard methods, he should examine the gem under high magnification in order to build up a working knowledge of the internal characteristics of gemstones.

Lighting. Ordinarily a jeweler examines a gemstone with the light directed from behind the stone, with the result that inclusions appear as dark objects against a light background.

DARK-FIELD ILLUMINATION, in which the light is directed upon the stone from the side, is by far the best method of lighting for an examination of inclusions, since it not only enables the observer to locate imperfections more readily, but also aids identification of included crystals by revealing them as light objects against a dark background.

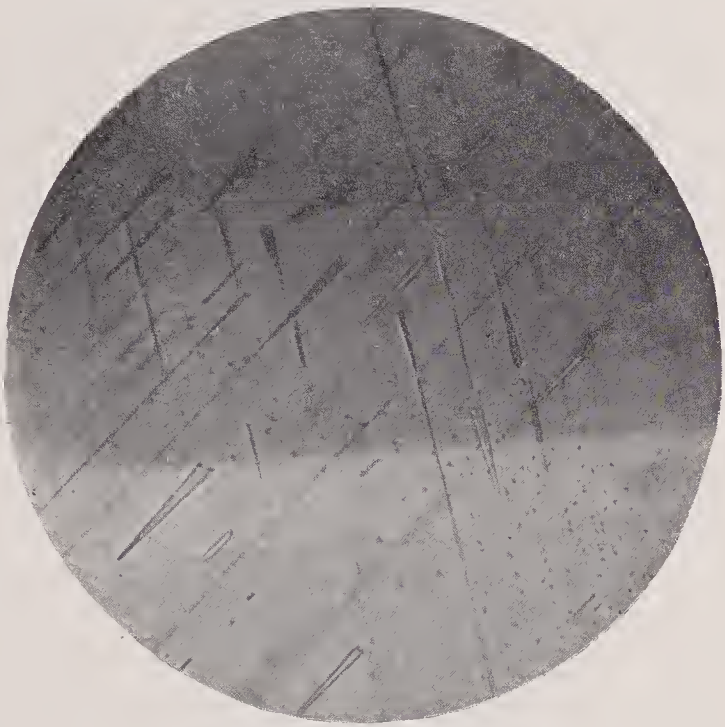

Photo by E. Gubelin

Figure 49

"Silk" formed by negative crystals in natural corundum.

Imperfections. Included under the term *imperfections* are surface and internal fractures and cleavages, gas and liquid inclusions, and crystal and other solid materials enclosed within the gem. In some gemstones the inclusions are sufficiently characteristic to permit an immediate identification of the stone.

Gemstones without internal flaw are not uncommon, especially in such gem species as diamond, beryl, topaz, and quartz.

Fracture. Four gems may be identified with some degree of certainty on a basis of their fractures.

Chalcedony has the conchoidal fracture common to most gems, but the luster on the fractured surfaces is dull or waxy, not glass-like as in other gems.

Hematite fractures are characteristically splintery, resembling a break in wood.

Turquoise is often identified by its dull to waxy luster on small fracture surfaces in contrast to the vitreous luster of its glass imitation.

Zircon derives a characteristic appearance from its strong tendency to "pit" or crumble at facet edges. Heat treated zircons are especially subject to such pitting.

Most other gems display a conchoidal or "shell-like" fracture. with a vitreous luster on the fracture surface.

Figure 50

Included zircon crystals surrounded by a "halo" of black fractures in natural corundum.

Cleavage. Since few gems of importance are likely to show cleavage, straight cracks in a gem are important as clues to its identity, while the angles between cleavage cracks may assist the jeweler to determine the system in which the gem crystallizes.

DIAMOND, the FELDSPAR GEMS, SPODUMENE, and TOPAZ are the common gemstones in which cleavage is likely to be observed. (See cleavage table, Appendix.)

Photo by E. Gubelin

Figure 51

Spinel octahedra as inclusions in natural sapphire with strong color zoning.

Important Genuine Gemstones and their Characteristic Inclusions.

Corundum. Study the photomicrographs of corundum (Figures 48 to 56) carefully. Usually the experienced gemologist can identify the corundum family under the microscope immediately by means of several types of characteristic inclusions.

The CRYSTAL INCLUSIONS encountered in ruby and sapphire have the following characteristic appearances:

Needle-like inclusions, known as "*silk*" consist of long *crystals of rutile,* straight and needle-like in appearance, and arranged in three sets of parallel threads which intersect each other at sixty-degree angles. The three sets are all in planes at right angles to the c-axis (in this case also the optic axis). Rutile or hornblende needles in almandite are usually, but not always.

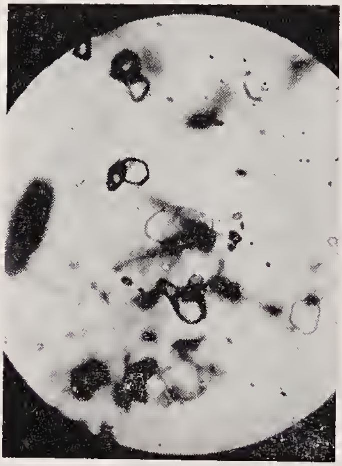

Figure 52

Six-sided mica and other angular inclusions in sapphire.

Figure 53

Photo by E. Gubelin

"Fingerprint" patterns of liquid inclusions in natural sapphire.

coarser than those in corundum. They differ distinctly, in that only two sets (at 70° to one another) occur in the same plane. Needle-like inclusions in quartz are very short, usually occurring in small bundles with three directions at 60 and 120° to another in each grouping.

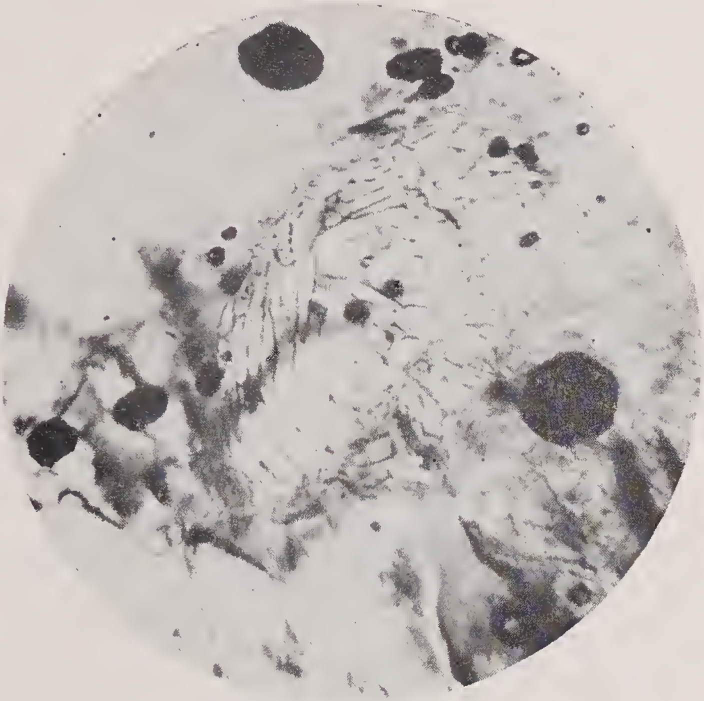

Photo by E. Gubelin

Figure 54

Solid six-sided opaque inclusions and liquid inclusions in a Siam ruby.

Included zircon crystals are characteristically *surrounded by a halo of black fractures.* Zircon, with its higher refractive index, stands out against the surrounding corundum as a bright point of light. The black halo of fractures around zircon crystals is thought to be caused by radioactive disintegration in the zircon.

Tiny spinel octahedra (eight-sided crystals that resemble two pyramids base to base) are found in corundum, especially in rubies from Burma and sapphires from Ceylon.

Other solid crystal inclusions which may be encountered in ruby and sapphire are:

Mica inclusions, six-sided, colorless or brown.
Hematite slabs, brown or black, (often with a hexagonal outline).
Garnet in rounded grains.
Rutile in coarse crystals.
Corundum crystals and grains with low relief.

The "FINGERPRINT" INCLUSIONS (Figure 53) take their name from interesting clouds of hollow inclusions filled with liquid and gas that form patterns resembling fingerprints around crystal inclusions. Though similar inclusion-filled planes occur in other gems, the liquid inclusions rarely have the regular pattern common in ruby and sapphire.

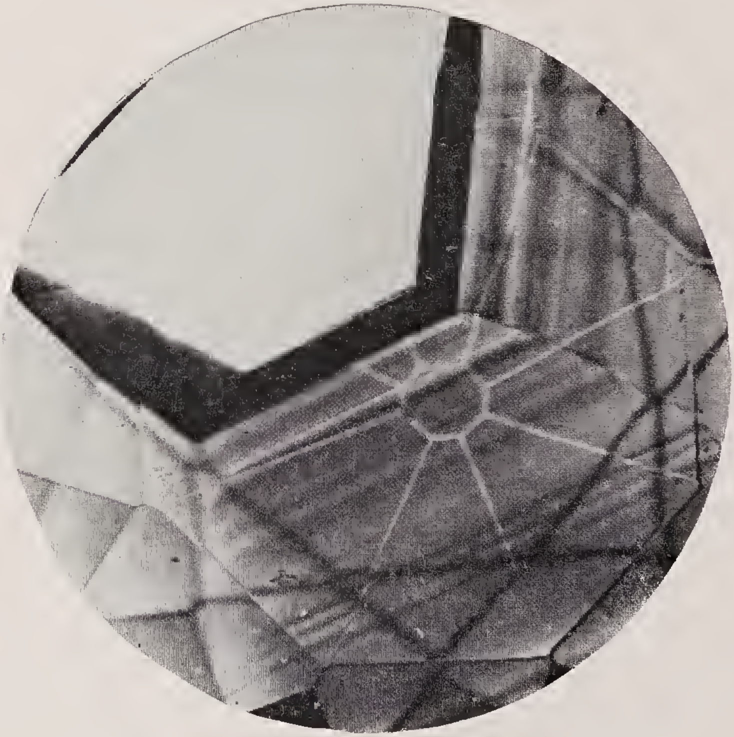

Photo by E. Gubelin

Figure 55

Strong hexagonal color zoning in natural corundum.

Siam rubies are characterized by the "fingerprint" inclusions, black solid inclusions and a lack of "silk" common to corundum from other localities.

Very prominent hexagonal growth and color zones are common in both ruby and sapphire (Figure 55). In Burma rubies, however. a streaked and wavy color distribution is characteristic.

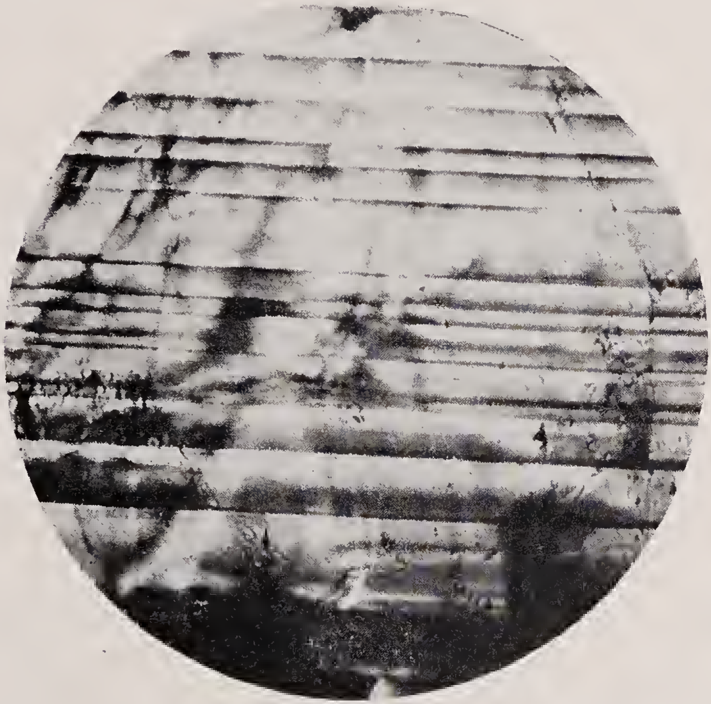

Photo by E. Gubelin

Figure 56

Straight parallel zoning caused by repeated twinning in corundum.

An effect created by repeated twinning constitutes an interesting phenomenon occasionally seen in corundum — the only colored gem likely to show it. Straight parallel lines, more widely spaced than "silk" or color-zoning striae, extend all the way across the gem. When the twinned stone is placed in the dark (crossed Nicols) position in the polariscope, or under the polarizing microscope, the gem remains light in all positions and does not exhibit the usual four light and four dark positions of a doubly refractive gem during a three hundred and sixty-degree rotation. A second set of such lines may be present at right angles to the first.

Tourmaline. RED TOURMALINE (rubellite) is typified by *many internal fractures* which are roughly parallel to the long axis of rubellite crystals. The fractures are usually gas-filled and give mirror-like reflections.

GREEN TOURMALINE seldom contains fractures parallel to the long axis of the crystal. It is characterized by *long, irregular, thread-like liquid and gas inclusions* evenly distributed in abundance throughout the gem. Rubellite has these same capillary-size liquid inclusions, but seldom in the abundance common in green tourmaline. The numerous tiny liquid inclusions of green tourmaline have an appearance unlike other gems.

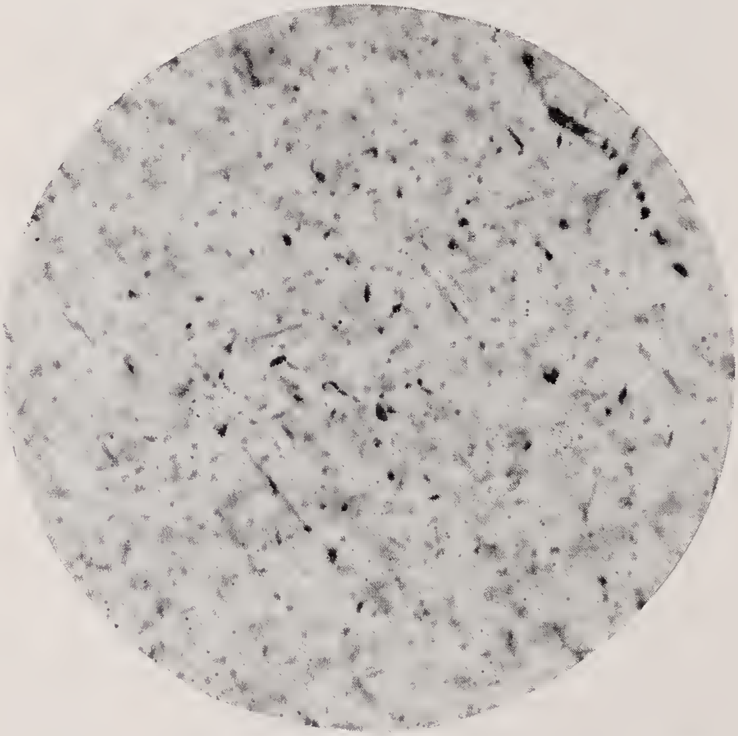

Photo by E. Gubelin

Figure 57

Typical inclusions in almandite garnet.

Garnet Group

Almandite. *Under magnification* ALMANDITE GARNET is likely to be confused with ruby, since it *sometimes contains grains of radioactive zircon as well as "silk" in a pattern that may appear similar to that found in ruby.* There, however, the similarity ends.

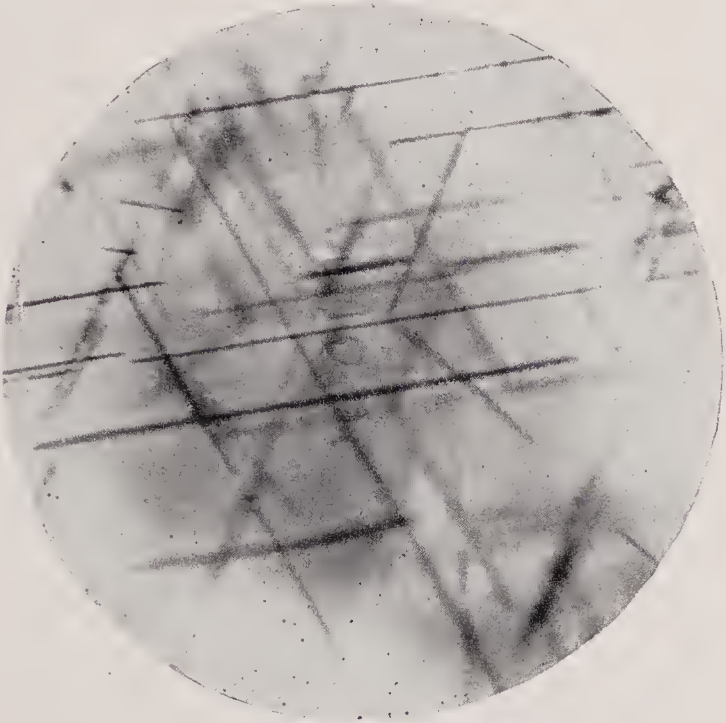

Photo by E. Gubelin

Figure 58
"Silk" in almandite garnet.

Almandite garnet is frequently observed in which one can see two sets of needle-like inclusions intersecting at angles of 70° and 110°. The angle of 70° is close to, and might be mistaken for a 60° angle on casual inspection. Since there are three such paired sets of inclusions in some almandite, there are certain directions along which a three-fold grouping of inclusions similar to that of corundum may seem to be present, however, only two directions are ever found in the same plane in garnet.

The "silk" in almandite is *coarser and shorter,* and usually *less abundant* than its counterpart in corundum. Evenly distributed small, colorless grains in great abundance that are often doubly refractive in the singly refractive garnet, together with the stubby "silk," suggest almandite.

Grossularite. GROSSULARITE GARNET usually contains *short, stubby, rounded prisms* (probably of diopside) *in quantity.* A characteristic peculiar to the HESSONITE VARIETY of grossularite is a *swirled "heat-wave-over-hot-pavement" effect* which gives the observer the impression that it is impossible to properly focus his microscope on the interior of the gem. (See Figure 59.)

Andradite. The *demantoid variety* of andradite garnet exhibits brown inclusions similar to *very fine "silk"* in *character-*

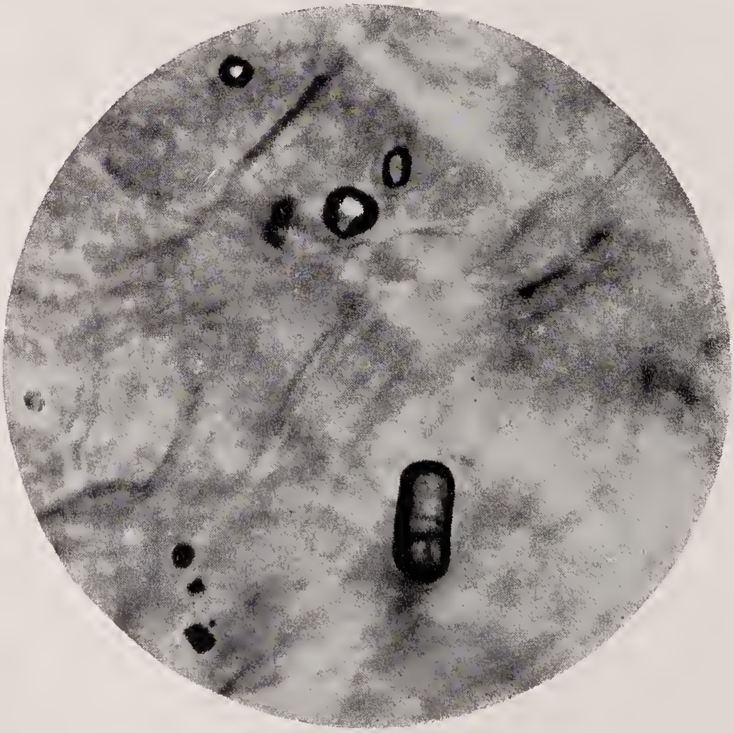

Photo by E. Gubelin

Figure 59

Stubby rounded prisms and swirled effect typical of hessonite.

istic curved and radiating arrangements, which identifies it at once (Figure 60).

Pyrope. Pyrope garnet has an internal appearance similar to that of almandite, but often with large rounded crystal grains and liquid inclusions of very low relief.

Beryl

Emerald. Emerald, one of the gemstones most easily identified by its imperfections, contains not only *many crystal inclusions*, but *also three-phase inclusions — irregular spaces filled with solid, liquid and gaseous matter.*

Photo by E. Gubelin

Figure 60

Characteristic "horse-tail" inclusions that identify demantoid.

An examination of its three-phase inclusions often establishes the locality in which the emerald was mined. Colombian Emer-

ALDS contain *tiny, tabular crystals which appear square,* in spaces partially filled by liquid and gas (Figure 61). URALIAN OR RUSSIAN EMERALDS contain *tiny, flat, diamond-shaped crystals* within gas and liquid-filled inclusions[1] (Figure 62).

The characteristically shaped *brass-yellow cubic crystals of pyrite* are often seen in emerald, and because they appear black in transmitted light, are usually referred to as carbon (Figure 63).

A badly fractured appearance is very common in emerald under magnification. Calcite inclusions along fractures are common in emeralds from Colombia.

Aquamarine. Though AQUAMARINE is often free from inclusions, it may show characteristic *brown, iron oxide inclusions* and *tiny, parallel liquid-filled spaces.*

Photo by E. Gubelin

Figure 61

Three-phase inclusions in emerald with a square crystal, indicating Colombian origin.

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[1] "Differentiation between Russian and Colombian Emerald" by Edward Gubelin, Gems & Gemology, Summer, 1940, pages 89-92.

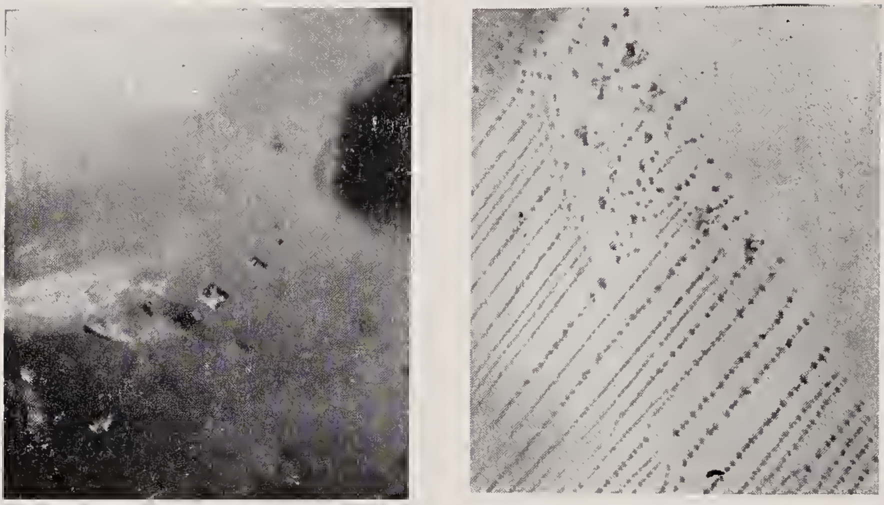
Figure 62

The diamond-shaped tabular crystal in this three-phase inclusion in an emerald indicates Russian origin.

Photo by E. Gubelin

Figure 63

Pyrite inclusions in a Colombian emerald.



Photos by G.I.A.

Figure 64

Octahedral spinel crystals in spinel.

Numerous octahedral spinel crystals which typify natural spinel.

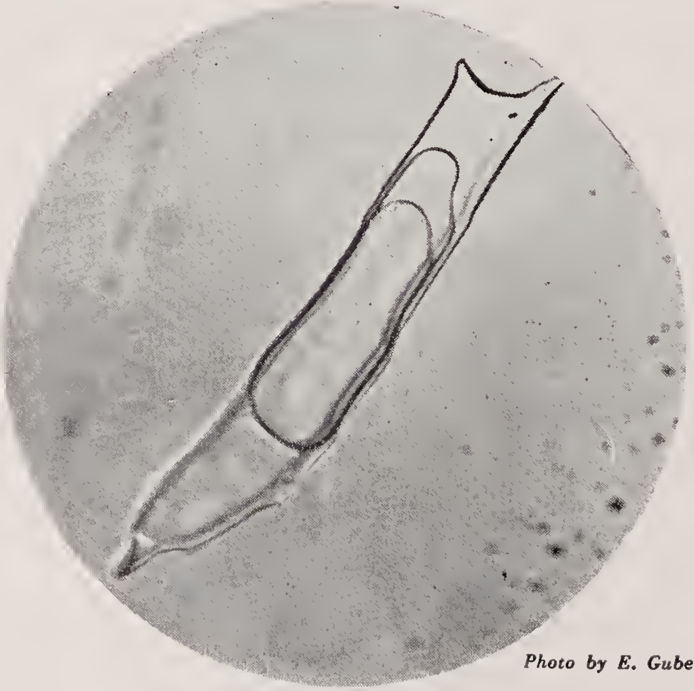


Photo by E. Gubelin

Figure 65

Irregular gas-and-liquid-filled space in topaz. Two liquids which are not miscible are enclosed.

Other Gemstones

Spinel. SPINEL'S characteristic inclusions are usually formed by tiny enclosed octahedral (eight-sided) crystals of spinel. The included crystals are found both scattered in a random distribution, and in layers of many crystals. The layers of crystals are sometimes parallel to octahedral faces of the spinel where they formed as the crystal grew, but more often these are distributed along irregular fractures.

Topaz. TOPAZ is more likely to be free from inclusions than almost any other important gem. Its characteristic inclusions are irregular, often fairly large liquid and gas-filled spaces, which may contain two or more non-miscible liquids separated by a clear dividing line (Figure 65). *The easy cleavage* parallel to the base of the orthorhombic topaz crystal *is sometimes shown in the cut gem by straight feathers.* No other gem in the topaz color range is likely to show cleavage traces.

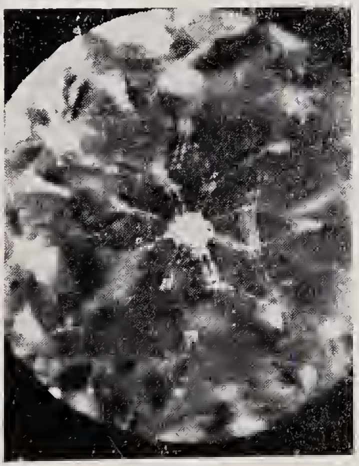


Photo by G.I.A.

Figure 66

Doubling of back facet edges in zircon under 10X magnification.

Zircon. Zircon does not have distinctive features likely to be encountered in a majority of stones examined. However, the sum of common features provides a valuable indication of identity.

The high birefringence of *all but green zircon* results in

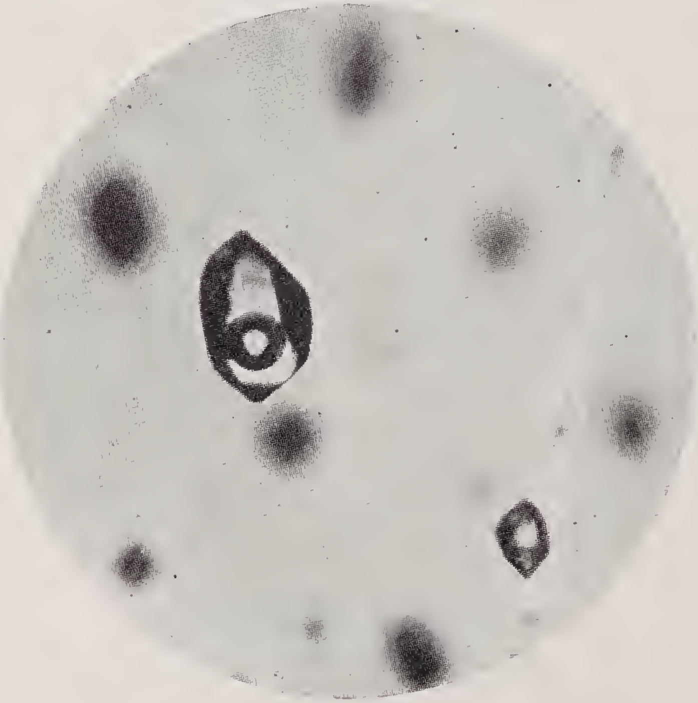


Photo by E. Gubelin

Figure 67

Liquid and a gas bubble in negative crystals in rock crystal quartz.

Figure 68

Moss-like arrangement of manganese oxide in moss agate quartz.

a strong doubling of the back facets in zircon of any other color. The junction of two facets appears to be two lines when the microscope is focused through the gem onto the pavilion facets. Similarly, *inclusions in all but green zircon* appear doubled, in any direction at more than a small angle to the axis of single refraction.

White zircon often has many inclusions so tiny that they cannot be resolved individually, but give a total *effect* referred to as "*cottony.*"

Zircon, unlike diamond, *appears cloudy*, rather than clear or sharply transparent.

Occasionally zircon contains *flat planes of worm-like inclusions, roughly circular* in contrast to the angular-patterned liquid inclusions of the corundum "fingerprint."

Photo by E. Gubelin

Figure 69

A colorless octahedron of diamond as an inclusion in diamond (taken under dark-field illumination).

Quartz. The species QUARTZ has more gem varieties than any other mineral. The crystalline varieties AMETHYST, CITRINE, ROCK CRYSTAL and SMOKY QUARTZ are characterized by inclusions of *negative crystals in the usual hexagonal crystal form of quartz.* However, crystalline quartz is often flawless.

Photo by E. Gubelin

Figure 70

Zircon crystals included in diamond.

Cryptocrystalline quartz (CHALCEDONY) has no inclusion typical of all varieties. The *dendritic arrangement of manganese oxide* in MOSS AGATE is characteristic of that variety.

The INCLUSIONS THAT CAUSE A STAR IN QUARTZ are unlike those that produce asteriated ruby and sapphire. The *needle-like inclusions are very short and occur in small "bundles" distributed at random throughout the gem.* Each of the tiny "bundles" consists of three sets of needle-like inclusions at 60° to one another. Star quartz seldom appears in the jewelry trade without a red or blue mirror backing to give color and to strengthen the star.

Peridot. Tiny black metallic inclusions, surrounded by a small "fingerprint" pattern of liquid inclusions, characterize peridot when present, but many peridots do not contain such inclusions. Peridot is strongly birefringent.

Diamond. The several inclusions which may be observed in DIAMOND, characteristic of the gem, are:

Tiny included crystals of diamond (likely to be confused with black carbon inclusions unless viewed properly; i.e., by dark-field illumination). Elongated, four sided prismatic colorless crystals that may be zircon are not uncommon. However the three keys to diamond identification under magnification are the unique appearance of the surface of a bruted girdle on a

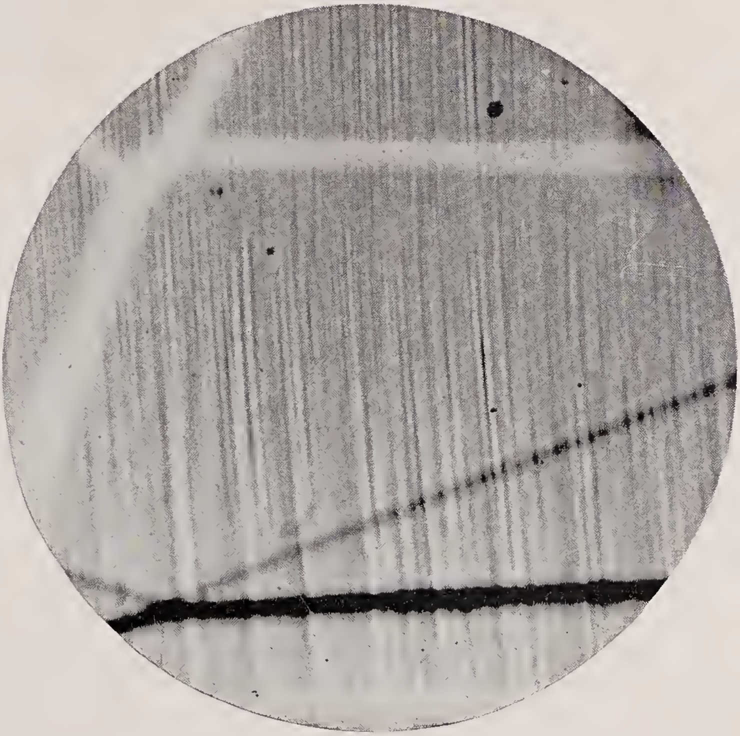


Photo by E. Gubelin

Figure 71

Spherical gas bubbles and curved striae in synthetic ruby.

brilliant or marquise, a grooved or trigon-studded natural (an original crystal surface), and cleavages. These together with luster, brilliancy, and dispersion permit certain identification by the gemologist.

SYNTHETIC GEMSTONES AND THEIR CHARACTERISTIC INCLUSIONS

In many cases the standard tests for identification of a gemstone will preclude the necessity of an examination of its inclusions, since so few gem species are synthesized. Differentiation between genuine and synthetic stones, however, depends upon the jeweler's ability to recognize inclusions characteristic of each gem. Since synthetics are quite common on the present market, the value of a sound knowledge of the characteristic in-

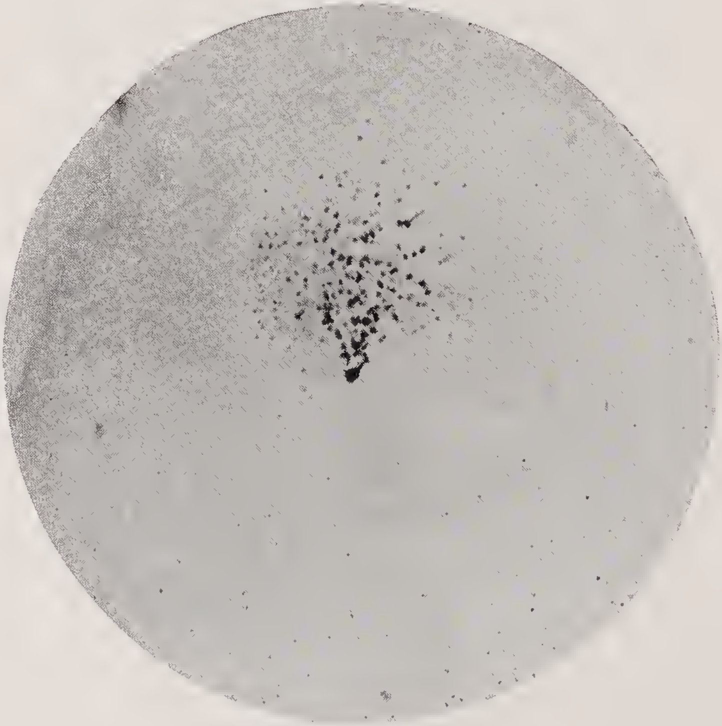


Figure 72
A patch of tiny spherical gas bubbles in synthetic corundum.

clusions of gemstones is emphasized, for the jeweler is frequently called on to distinguish between a genuine and a synthetic stone.

The three important gems made synthetically have characteristic differences under high magnification. Although inclusions commonly found in synthetic corundum, spinel, and emerald are discussed in the chapter on synthetic gemstones, they are of such importance to the jeweler in identifying gems that it is well to describe them here as well.

Synthetic Corundum. *Spherical gas bubbles* are characteristic of SYNTHETIC CORUNDUM and may have the following appearance and arrangements:

They may be *round in cross-section, but elongated,* like a bubble which has risen from its original position in a molten material.

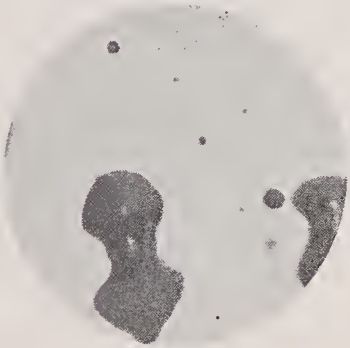


Figure 73

Large profiled and tiny spherical gas bubbles in synthetic spinel. Minute spherical bubbles are much more commonly seen than large ones.

They may be found in *groups of many tiny bubbles,* frequently *with one or two large bubbles* in addition, or as *rough lines of bubbles arranged on a curve.*

Curved growth lines. or striae, are often evident in synthetic corundum, and are characteristic. (See Figure 71.) (See Chapter X.)

Caution: Since polishing marks on a facet may resemble striae, be sure to focus the microscope on a point within the gem when observing the stone for curved striae, and be certain that the striae continue across several facets.

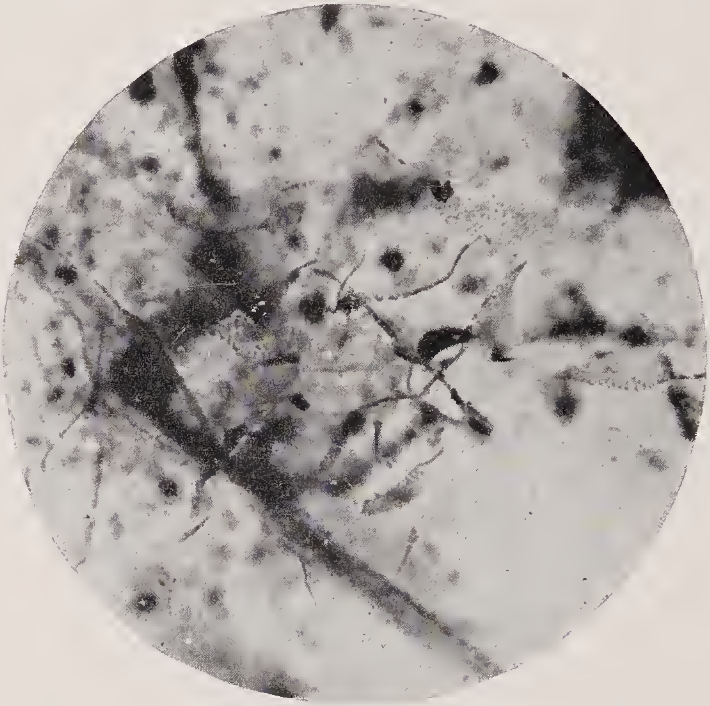


Photo by G.I.A.

Figure 74

Wisp-like patterns of liquid inclusions in synthetic emerald.

Synthetic Spinel. *Spherical gas bubbles, usually very small and quite widely separated,* rarely grouped, are characteristic of SYNTHETIC SPINEL.

Small inclusions which have the appearance of white bread crumbs in dark-field illumination also characterize synthetic spinel. (See Figure 73.) but are less commonly encountered.

Very rarely curved color bands are visible in synthetic spinel, but *never* curved striae in any color but red.

Synthetic Emerald. SYNTHETIC EMERALD is distinctly different from either synthetic spinel or synthetic corundum in that it contains no spherical bubbles and never has curved growth lines.

Its inclusions have *a deceivingly genuine appearance.* Indeed, the new American-made synthetic emerald bears such a close resemblance to the genuine gem that it is unwise for the inexperienced jeweler to attempt to distinguish between the two by means of inclusions. Natural emerald often show three-phase inclusions (solid, liquid, and gas within the same space). Colombian emeralds have tiny square crystals and Russian emeralds have diamond shaped crystals in the spaces partially filled by liquid and gas. Pyrite crystals are common in natural emerald. The Chatham synthetic usually contains crystals of platinum. These cubic crystals are white. in contrast to the brass yellow of the pyrite crystals in the natural. They are usually close to the surface. Platinum is soft and sectile. in contrast to hard, brittle pyrite. A needle point will distinguish between the two in crystals at the surface. Chatham synthetic emeralds also are characterized by the presence of wispy or veil-like groups of liquid and gas inclusions. The appearance illustrated in Figure 74 is unlike any pattern observed in genuine emerald; but for the novice. the lower property values in conjunction with fluorescence under long-wave ultraviolet, furnishes a safer means of identification. (See Chapter X.)

The new synthetic emerald-coated beryl (Linde synthetic emerald) is characterized by parallel cracks in the thin coating. Within the large preformed seed, natural beryl inclusions are to be expected. The overgrowth is not polished on most facets. so tiny crystal faces are visible under magnification.

Reconstructed Ruby by definition would be man-made ruby produced by using fragments of natural ruby. Apparently, sintering was never used, but it is apparent that small button-shaped rounded synthetic rubies were made before the advent of the Verneuil Process. Such synthetic or reconstructed ruby had sets of curved striae meeting other sets at abrupt angles. A somewhat similar striae condition could exist at the tip of modern boules started on synthetic seeds.

Figure 75

Reconstructed ruby under 30X. Note curved lines on left meet those on the right at a sharp angle and end abruptly.

Glass. *Spherical or elongated gas bubbles and swirl marks,* or flow lines, characterize glass. The latter are caused by incomplete mixtures of the ingredients of the melt or are formed by pressure as the glass is molded into its faceted gem appearance.

Often *insoluble angular material* is mixed with glass to simulate the genuine inclusions of certain species of gemstones. Such inclusions are seldom an accurate representation of those of the genuine gem, but a hasty examination may lead to an incorrect identification. Glass is often flawless.

Synthetic Rutile. The spherical gas bubbles that characterize synthetic corundum and synthetic spinel are also to be found in synthetic rutile. The most unusual feature of the new material under magnification is the tremendous doubling of back facet junctions and of any inclusions that may appear. In even small faceted stones, the birefringence causes two entirely separate culets to be seen (Figure 45, page 78).

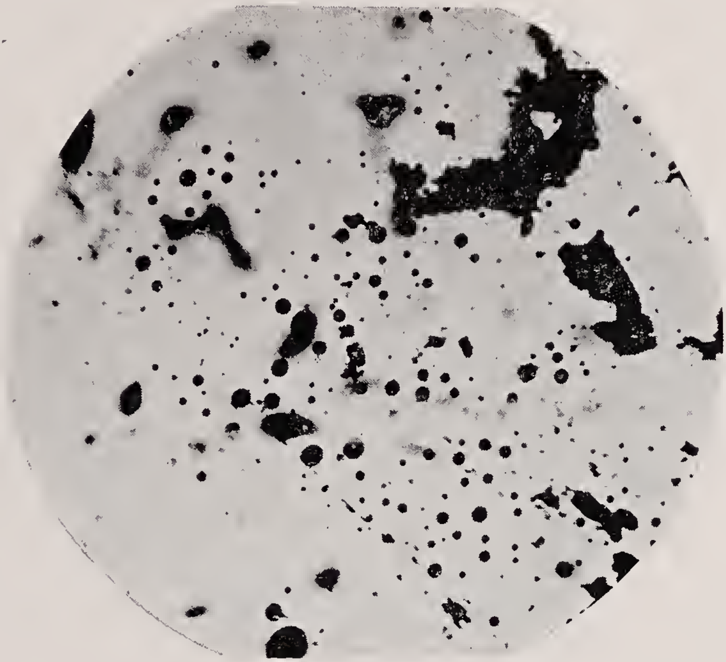


Figure 76

Spherical gas bubbles and irregular solid matter in a glass imitation of emerald.

Strontium Titanate. This Verneuil product is similar to the others in that it usually contains spherical gas bubbles.

Conclusions.

It is manifestly impossible to convey by word alone a sufficiently accurate description of characteristic inclusions so that the reader will be able to identify a gemstone simply on a basis of its appearance under high magnification. The purpose of this chapter is to call to the attention of the reader the possibilities of the use of a gem's imperfections as a means of identification which will become increasingly valuable to him as he becomes more adept at gem testing.

Chapter IX

Color Filters and Fluorescence

Sunlight and the light from other incandescent light sources is made up of a blend of the colors of the spectrum. The white light we see may be made up of all spectral colors or just some of them. To appear colorless to the eye, gemstones must either transmit all of the spectral hues or enough to achieve a balanced transmission the human eye perceives as white. Colored stones are seen as colored because of a selective absorption of some of the wave lengths of the white light transmitted. Differences in absorption of the various wave lengths cause differences in appearance, such as those characterizing ruby, red spinel, red tourmaline, and the red garnets, for example. A keen eye, familiar with the characteristic appearances of the various gemstones, may be able to distinguish between even very similarly appearing gemstones with a high degree of accuracy. However, to identify beyond question, other devices than the human eye are needed, for the eye is incapable of analyzing the composition of a light, whether colored or white. To assist the eye, the gemologist employs such devices as the dichroscope, color filters, and the spectroscope. The function of the dichroscope was explained in Chapter VI.

The Emerald Filter. Of the color filters used for various purposes in science, that of greatest use to the gemologist is that known variously as the Chelsea, or emerald filter. The transmission curve of the emerald is unusual among green gemstones, in that a portion of the yellow-green spectrum is largely absorbed by emerald and a major portion of the deep red is transmitted. Anderson and Payne, of the London Laboratory, prepared a filter that permitted the passage of little green, except that in the yellow-green wave lengths, but permitted the transmission of the deep-red wave lengths. Since the portion of the green and yellow-green spectrum transmitted by most emeralds is absorbed by the filter, only the deep-red secondary peak of emerald transmission is seen through the filter. As a result, most (but not all) emeralds and synthetic emeralds appear red through the filter, in contrast to most other green gems and substitutes. Other green gems, lacking the yellow-green absorption of emerald, usually appear green. Demantoid and green zircon often have a pink appearance, and green plastic-coated beryl may appear red. Some emerald imitation triplets have a green cement that makes them appear red through the filter, but these are exceptions. Most doublets and triplets, jadeite, tourmaline, glass, and green chalcedony appear green. Occasionally, dyed jadeite and green chalcedony that has been dyed takes on a pinkish color when seen through the filter.

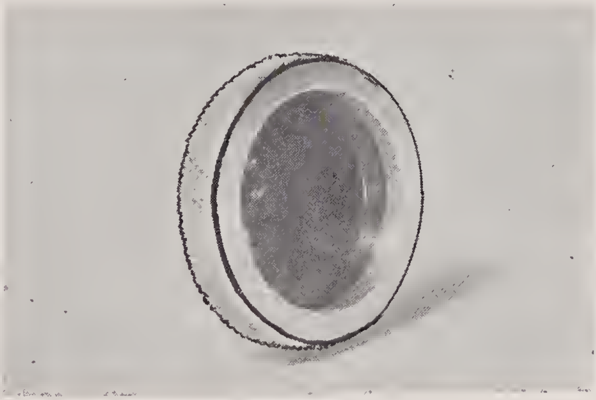


Figure 77
The Emerald Filter.

How to Use the Emerald Filter. To use the emerald filter, hold the gem over or beneath a strong white-light source and examine it with the filter held close to the eye. The value of the emerald filter in testing green stones is limited not only by the exceptions to the expected behavior, as indicated earlier, but also by the fact that the appearance of the Chatham synthetic is substantially identical to that of the fine natural stone. Moreover, certain mines, notably

Indian and African produce stones that remain green under the filter.

Synthetic blue spinel also appears red through the emerald filter in contrast to most genuine spinel and other blue gems which spinel imitates. However, natural spinel sometimes shows red through the filter. It is unwise to decide upon the natural or synthetic character of spinel on the basis of such a test, when more effective means of detection of the synthetic are available.

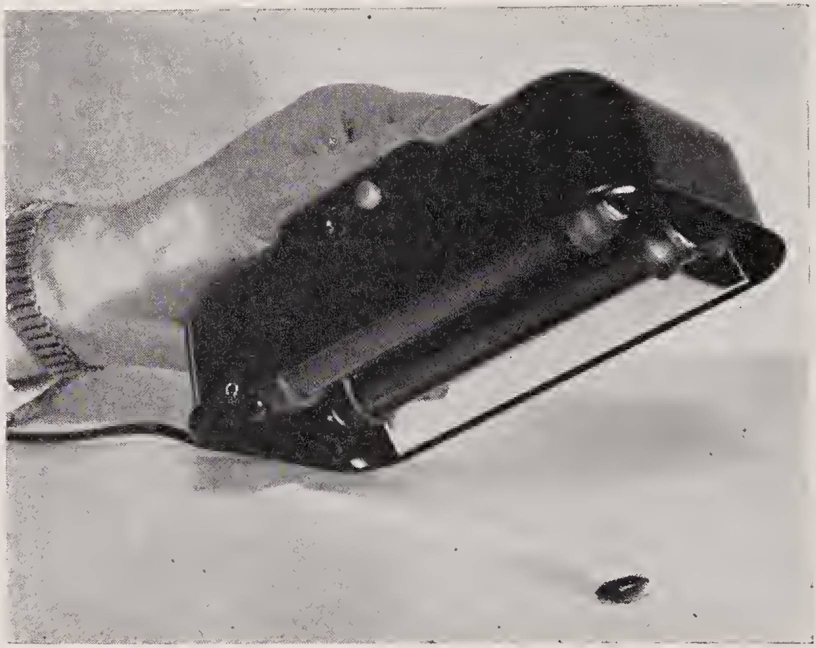


Figure 78

The G.I.A. Fluorescent Unit.

Fluorescence and Phosphorescence. When radiation shorter in wave length than visible light (ultra-violet or X-rays) falls upon certain materials, they have the property of transforming the invisible radiation to wave lengths of visible spectrum range. This property is called FLUORESCENCE. If the light emission continues after the object has been removed from the source of excitation, the material is said to be PHOSPHORESCENT. Since the color of the fluorescence is often distinctive for certain gemstones, it is sometimes a certain test, but more often merelý an indication of a gem's identity. Ultra-violet light sources of two wave lengths are most commonly used: certain materials will fluoresce under a radiation with a wave length of 2500Å., while others are more strongly affected by radiation of 3500Å. The 2500Å. radiation is furnished by a lamp

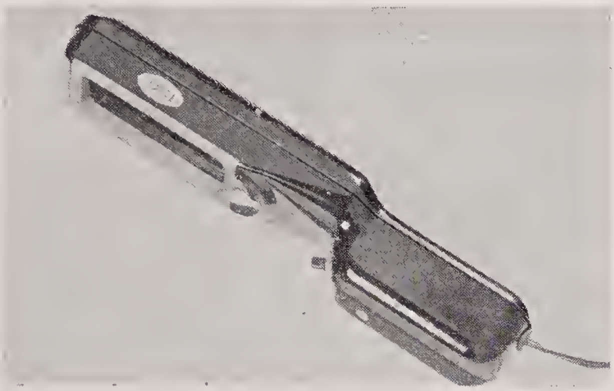


Figure 79

The Mineralight

2537Å., while others are more strongly affected by radiation of 3660Å. The 2537Å. radiation is furnished by a lamp known as the Mineralight. Radiation of 3660Å. is provided by the G.I.A. Fluorescent Unit or another Mineralight model. The filter on the short-wave ultra-violet lamp is critical. After about 400 hours of use or not more than one year of elapsed time, the filter should be replaced, for it loses its effectiveness in filtering out long-wave ultra-violet. When this happens, its value in several tests is reduced or lost. The filter should be kept free of a surface film of dirt or tarnish.

About 15% of gem diamonds fluoresce strongly under the 3660Å. light, but usually show less flouorescence under the shorter wave-length radiation. Diamond flourescence is usually a light blue, but can be almost any color of the spectrum. The type of diamond known as Premier always fluoresces very strongly, usually in a light blue color. Under short-wave ultra-violet, blue synthetic sapphire fluoresces slightly, giving an appearance of a yellowish smudge. It is best observed in a dark room. Natural yellow sapphires from Ceylon fluoresce, but synthetic yellow sapphires fail to fluoresce under long-wave ultra-violet. Chatham synthetic emeralds always fluoresce and natural emeralds almost always fail to flouresce under long-wave. The fluorescence is best seen if the test is performed in a dark room with the stone placed on a dull black background. Failure to fluoresce may be regarded as proof of natural origin. There are many other separations in which reaction to ultra-violet light is useful in identification.

Many triplets and garnet-and-glass doublets can be detected at one time by the use of the fluorescence test. Glass bases on garnet-and-glass doublets usually fluoresce a greenish-yellow under 2537Å. The nonfluorescent garnet stands out as a dark spot on the fluorescent background. The cement layers of some triplets fluoresce strongly, thus standing out clearly from the top and base of the imitation. It is possible that synthetic emerald will be made that fails to fluoresce or that a source of fluorescent natural emerald with the same fluorescent color and strength will be discovered, but until that time, this simple test will prove effective.

Transparency to Ultra-Violet. Another property sometimes employed in testing is transparencey to ultra-violet radiation. Using a quartz spectrograph, B. W. Anderson noted that whereas natural emerald failed to transmit wave lengths below about 3000Å., the Chatham synthetic transmitted down to about 2300Å. Another British gemologist Norman Day proposed a test to utilize this difference in testing; however, it requires darkroom facilities and supplies, plus exacting exposures. Unknowns are placed on photo print paper in a dish of water (use nonfluorescent glass) and given a short exposure (usually a fraction of a second) to a short-wave ultra-violet lamp. Both synthetic ruby and Chatham synthetic emerald transmit the light and expose the paper, whereas the natural stones appear to be opaque to the lamp. A generally more satisfactory test to detect this difference in transparency to ultra-violet is described under Chatham synthetic emerald in the next chapter.

Chapter X

Synthetic Gemstones

A synthetic gemstone is one that has the same chemical composition, crystal structure, and, consequently, the same physical and optical properties as those of the natural gem it represents. Since its properties are the same as those of its natural counterpart, such important tests as the determination of refractive index and specific gravity are valueless in the detection of the synthetic. Fortunately, the only gemstones synthesized in commercial quantities are corundum, spinel, emerald, and rutile or Titania. The synthetic zircon, garnet, topaz, amethyst, aquamarine, and alexandrite of the trade are actually synthetic corundum or synthetic spinel. Since these stones do not have the same properties as the gems they represent, little difficulty is encountered in their detection. Synthetic corundum and synthetic spinel are also incorrectly sold as reconstructed gems. *Reconstructed* gems are those which are formed by melting small pieces of the natural material. Rubies are known to have been reconstructed at one time, but are rarely encountered in the American jewelry trade today. No other gems are manufactured by reconstruction at the present time, but so-called reconstructed ruby, sapphire, emerald, and many other gems are offered for sale in the trade. They are usually the common synthetic corundum or synthetic spinel, but glass imitations are not uncommonly sold as reconstructed gemstones.

SYNTHETIC CORUNDUM

Manufacture. Synthetic corundum is produced by the Verneuil Process. It is now manufactured in the United States in large quantities, mostly by the Linde Air Products Company. Powdered aluminum oxide is dropped through an oxy-hydrogen

Figure 80

A Verneuil Oven with half-formed boule in position.

flame in which it melts before falling upon a slowly revolving ceramic rod. As the molten alumina solidifies, it assumes the crystal structure of natural corundum. The *boule* resulting from the accumulation of molten drops of aluminum oxide may weigh hundreds of carats. Because of the internal strain which is always present, the pear-shaped rough boule must be split lengthwise before cutting. If the aluminum oxide which comprises corundum or synthetic corundum is pure, the crystalline material is colorless. The addition of small percentages of certain metallic oxides lends color to the synthetic product. Synthetic corundum is produced in most of the colors in which corundum is found in nature as well as many not occurring naturally.

Although man must add slightly higher percentages of the metallic oxide coloring agents to produce colors comparable to those of natural corundum, no significant changes in physical and optical properties result. The specific gravity of the synthetic is within .03 of 4.00, the average figure for natural corundum; the principal refractive indices are 1.762 and 1.770, and the birefringence is .008 — exactly the figures for nature's product.

Figure 81
Stages of boule growth.

Synthetic Star Corundum. In 1947, the Linde Air Products Company introduced synthetic star corundum in red and blue colors. The asterism is caused by needle-like rutile inclusions so minute that magnification of at least 50X is required to resolve them.

Linde produces the synthetic star corundum by heating boules containing .1% to .3% titanium oxide to from 1100° C. to 1500° C. Heating for from two hours at 1500° C. to 72 hours at 1100° C. brings about precipitation of the titanium oxide along the three directions parallel to the normal prism faces of corundum in the basal plane. If more than .3% titanium oxide is used to make the original boule, it is very difficult to grow the boule. After the boule is heated to bring about precipitation of the titania (as rutile, apparently), it is fashioned with the base perpendicular to the optic axis (c axis) and reheated. Although the early products had the tiny rutile needles only in a surface layer, later synthetic star rubies and sapphires have the needles distributed throughout the stone. Brown and white varieties have been added to the original red and blue colors.

Transparent synthetic corundum, cut in a cabochon form with a flat back, is engraved with sets of fine parallel lines at 60° on the flat surface. Usually the back is covered by a foil or mirror and a flatly curved piece of synthetic corundum. Such foil backs have been offered as "synthetic star rubies" or "sapphires."

Distinguishing Between Corundum and Verneuil Synthetic Corundum

Conclusive Methods.

1. *The shape of inclusions* can be used to positively determine whether corundum is natural or man-made.

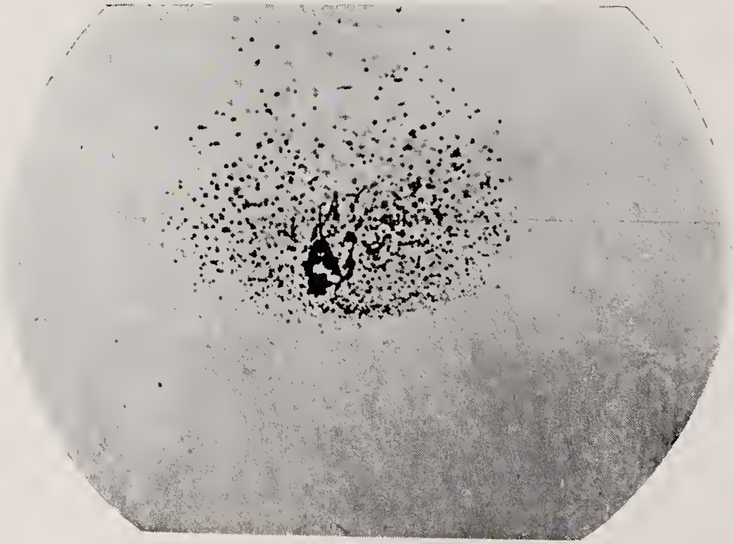


Figure 82

A patch of tiny spherical gas bubbles with a few irregular gas inclusions. The bubbles show as bright points in dark-field illumination.

a. Inclusions Characteristic of Synthetic Corundum.

Synthetic corundum is characterized by the presence of spherical gas bubbles. The bubbles are normally small, appearing as bright pinpoints of light when the gem is examined under magnification in dark-field illumination. The tiny spheres usually occur in groups or patches distributed unevenly throughout the gem, or confined to a single area. Occasionally a large spherical gas inclusion is found within a patch of tiny spheres. Bubbles are often arranged roughly in curves corresponding to the growth lines of the boule. It is not uncommon to find elongated gas bubbles resulting from movement of the viscous material during cooling. Such inclusions are circular in cross section in one direction, but elongated in the other. Some European synthetics contain irregular inclusions in addition to spherical bubbles, but, since spherical inclusions are not found in natural gemstones, little difficulty is encountered in their identification. However,

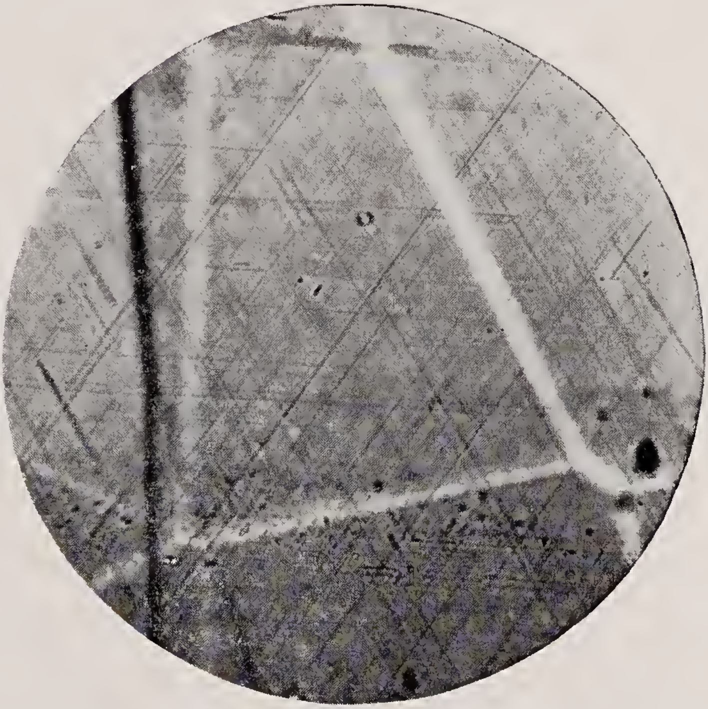


Photo by E. Gubelin

Figure 83

"Silk" in three groups of parallel needles of 60 degrees.

the detection of an irregular inclusion in a gemstone is no longer a proof of natural origin. Synthetic star ruby and sapphire seems to have more spherical gas bubbles than are common in faceted synthetics of recent manufacture. Transparent synthetic corundum entirely without bubbles is becoming increasingly common.

b. ***Inclusions which Characterize Natural Corundum.*** Natural corundum may be positively distinguished from the synthetic equivalent by its inclusions. Natural corundum has angular inclusions in contrast to the spherical bubbles found in the synthetic. Characteristic of the genuine stone is the prevalence of "silk." "Silk" is a loosely defined term applied in the gem trade to long, thin, needle-like inclusions found in genuine corundum. It is usually formed by the growth of long, thin, rutile crystals, but it may consist of very long, negative crystals (hollow cavities with a crystal shape). "Silk" is arranged in corundum in three sets of parallel lines at 60° to each other. (See Figure 83.) The presence of coarse "silk" (visible under 30X magnification) is indisputable evidence of the natural origin of corundum, however, natural corundum sometimes contains no needle-like inclusions. Synthetic star corundum also contains "silk," but the individual needle-like inclusions are tiny both in

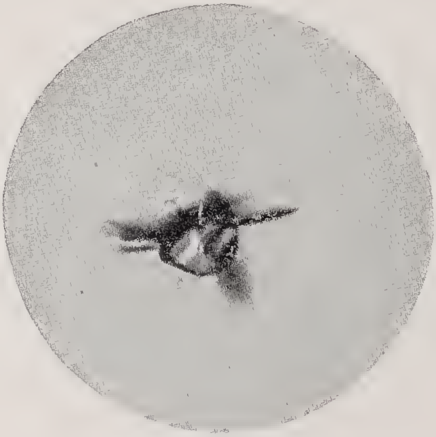


Figure 84
Zircon inclusions surrounded by a "halo" of tiny black fractures in sapphire.

length and cross-section, at least 50 magnifications being required to resolve them.

Other characteristic inclusions of natural corundum are tiny crystals of zircon, which stand out in bold relief because of the great difference in refractive index between corundum and zircon. The zircon usually appears as a point of bright light, surrounded by a "halo" of tiny black fractures. (See Figure 84.) Small octahedral crystals (eight sided solids resembling two pyramids base to base) of spinel are included in corundum, but small included crystals and rounded grains of corundum are more common. (See Figure 86.) Because of inclusions of corundum have the same index as that of the parent material, they exhibit almost no relief.

Planes of liquid inclusions that have an angular pattern are also common in genuine material. The fairly regular pattern

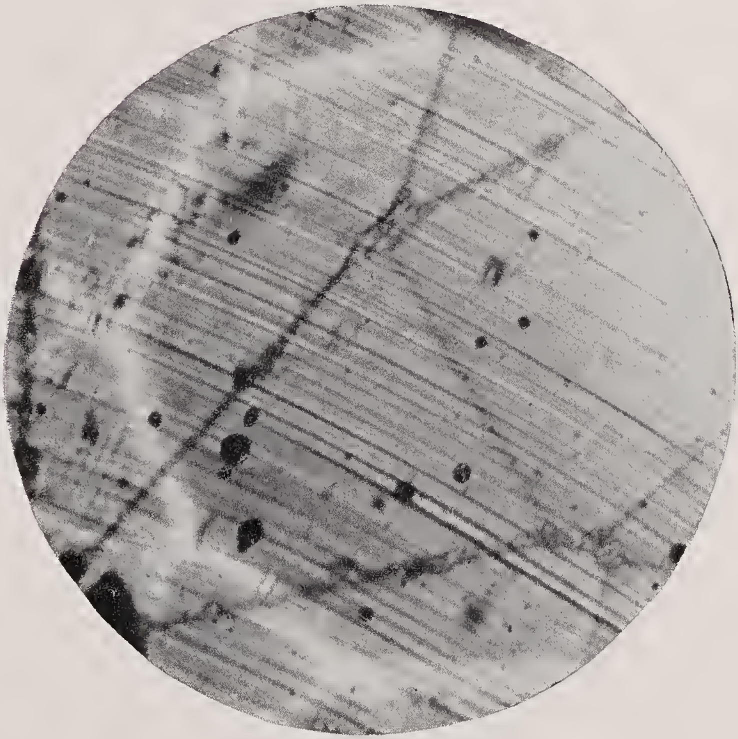


Photo by E. Gubelin

Figure 85

Curved striae and spherical bubbles with tails in synthetic corundum.

of liquid inclusions in ruby and sapphire have an appearance best likened to fingerprints. (See Figure 53.) Angular crystal and liquid inclusions are characteristic of material of a natural origin.

2. *Growth Lines.* The classification of growth lines is a reliable means of establishing the synthetic or natural origin of corundum.

a. *Synthetic corundum* is characterized by the presence of curved growth lines, or striae. As the synthetic boule is formed, the molten alumina flows outward from the center of the boule top. It is believed that a slight distortion of the crystal lattice of the doubly refractive material is the cause of the striae. The striae are visible when the finished gem is viewed perpendicular to the long axis of the original boule. They are most easily seen when the light source is reduced to pinpoint size, with the gem placed between it and the objective of the microscope.

Figure 86
Rounded corundum grains included in sapphire.

(See Figure 85.) Color zones with the same curvature are also commonly encountered in the older synthetic corundum. As in transparent synthetic corundum, curved striae serve to distinguish the synthetic from natural star corundum. The artificial gem material does not always exhibit curved striae, but the gemologist should develop a technique for magnification that will resolve curved striae whenever possible. The production of synthetic corundum free of inclusions is increasing; hence, it is becoming more important to detect striae with optimum efficiency.

Another method of detecting striae or color banding is to immerse the stone, preferably in methylene iodide or bromoform (or another liquid in its index range). If a clear-bottomed cell is used, a sheet of white paper inserted beneath the cell to a point half way across the light opening often brings out hard-to-see striae. Immersion in an opal-glass or milky polyethylene cell may also be helpful. Curved striae are usually obvious in synthetic alexandrite-like sapphire; easily detected in synthetic ruby; usually to be seen in synthetic blue sapphire; and detectable (if at all) only with difficulty in orange, green or yellow varieties, and rarely, if ever, seen in color-

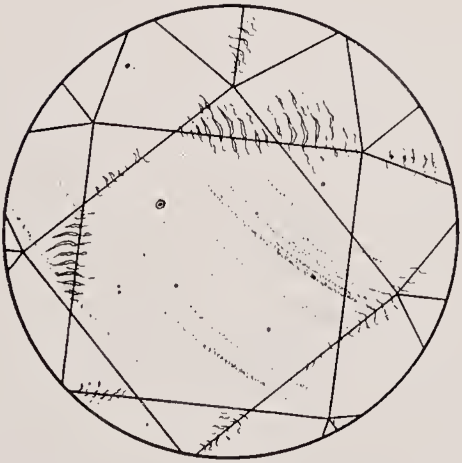


Figure 87

Typical cracks at facet edges, caused by rapid polishing; with spherical bubbles and curved striae in synthetic corundum.

less synthetics. In pale stones, try an immersion medium of about 1.55 to 1.60 in refractive index.

b. *Natural corundum* exhibits color zoning, inclusions arranged parallel to straight growth planes, and striae due to repeated twinning. Both color zones and inclusions parallel straight growth planes and intersect at angles of 60°, but the striae resulting from repeated twinning continue as straight lines entirely across the cut gem. A second set of twinning striae may occur at right angles to the first. Corundum often has irregular color distribution, with one growth layer strongly colored and the next almost colorless. This effect is rarely apparent unless the gem is observed parallel to the long axis of the original crystal (parallel to the growth lines). Although the zoning or the striae of natural corundum is usually more distinct than that of its synthetic counterpart, it is often necessary to subject natural corundum to the same careful scrutiny before arriving at a definite decision as to its identity.

Burma rubies often show an irregular color distribution that seemingly bears no relation to the growth of the crystal. This patchy color distribution is characteristic of the Burma ruby.

3. *Absorption Spectra.* There are a few colors for which spectroscopy furnishes reliable means of distinguishing between natural and synthetic corundum. The presence of iron in natural green, blue and yellow sapphire is made evident by absorption in the blue region of the spectrum. Green sapphire shows general absorption from about 4500Å to over 4600, with a separate band near 4700. In yellow and blue sapphires, the absorption varies with locality, from that described for green to three distinct lines near 4500, 4600 and 4700Å; or, sometimes, only a single vague band near 4500Å may be seen. Australian, Thai and Montana stones contain enough iron to show usually the three zones of absorption, whereas stones from Ceylon, low in iron, show only a weak band at 4500Å or none at all. Fortunately, natural yellows from Ceylon fluoresce, in contrast to synthetic yellow sapphire. Synthetics in these three colors show no absorption.

4. *Fluorescence.* Differences in reaction to ultra-violet radiation make it possible to distinguish some corundum varieties from synthetic counterparts, but the differences are usually so small that tests should be carried out in a completely dark room on a dull-black surface with knowns for comparison.

Both synthetic rubies and natural stones from Burma and Ceylon fluoresce strongly under long- and short-wave ultra-violet, but the synthetic is perceptably brighter when natural and synthetic are examined under short-wave side by side. Both glow under X-rays, but the synthetic phosphoresces and the natural does not. Siam rubies and garnet-red synthetics show little or no fluorescence under ultra-violet.

Under short-wave ultra-violet, synthetic blue sapphires usually show a yellowish fluorescence that appears to smudge the surface, but it is very easy to overlook. The natural is inert. In a group of synthetics, there is a wide variation in the strength of the reaction.

Synthetic yellow sapphires are inert to both long- and short-wave ultra-violet, as are natural yellow stones, except those from Ceylon. The latter glow richly in an orangy-yellow color under long wave.

Some synthetic colorless sapphire has a faint pale blue glow under short-wave ultra-violet. Some synthetic colorless material is inert.

5. *The Plato Method.* An effective method for the detection of synthetic corundum without flaw and without detectable curved striae is one developed by a German professor, W. Plato.[1] The optic axis direction is first located by use of the polariscope, and then the unknown is examined between crossed Polaroids under about 20-30X while immersed in methylene iodide. When a synthetic corundum is examined parallel to the optic axis direction under these conditions, three sets of lines at 60° to one another resembling repeated twinning lines identify synthetic corundum. The natural material shows no similar effect. Thus, this provides an excellent means of distinguishing flawless synthetic corundum without visible striae from flawless natural stones.

[1] Plato, Dr. W., Gems & Gemology, Fall, 1952.

Inconclusive Evidence of the Synthetic or Natural Origin of Corundum.

There are many other characteristics that could not be considered definite proof, but are indications of origin.

1. Because synthetic corundum has a negligible intrinsic value, little care goes into its fashioning. The heat generated by polishing synthetics too rapidly frequently causes cracks to appear at facet junctions. (See Figure 87.) Polishing or wheel marks on the surface of the facets are commonly seen in the synthetic. Cracks along the facet junctions and other evidence of poor polishing can be considered an indication of synthetic origin, except in calibre sizes.

2. Splitting the boule lengthwise to ease internal strain produces rough from which large gems are most advantageously cut when the table of the gem is placed parallel to the length of the boule. In this position, the optic axis is more or less parallel to the table, a condition which allows dichroism to be observed through the table. Natural rough, on the other hand, lends itself to the greatest preservation of size and beauty in the cut gem when the table is perpendicular to the optic axis. Thus, in most cases, no dichroism can be seen through the table of a natural stone.

3. Corundum cut with the scissors style of facet arrangement is almost always synthetic.

4. Early synthetic star corundum exhibited a transparency unknown in the natural star when viewed from the side perpendicular to the long axis of the cabochon-cut gemstone. Most synthetic stars produced after the first year of manufacture are nearly opaque and are marked by stars so pronounced that they are visible even under diffused light sources.

5. If corundum remains equally light in all positions upon rotation in the dark position of the polariscope or polarizing microscope, natural corundum is suggested since such an effect is caused by repeated twinning.

These five indications should NEVER be considered proof of natural or artificial origin.

Hydrothermal, or Flux-Fusion, Synthetic Corundum. In 1957, Bell Laboratories announced success in overgrowing synthetic ruby on prepared wafers of synthetic corundum by a hydrothermal process. In 1960, Carroll Chatham announced success in the production of synthetic ruby by a process similar to that used in his production of synthetic emerald. General Electric has announced the growth of thick, tabular synthetic ruby crystals from solution in molten lead fluoride. In mid 1962, these materials were not on the market nor available for study.

SYNTHETIC SPINEL

The chemical composition of both natural and synthetic spinel is magnesium aluminum oxide. There is a difference between synthetic spinel and the other synthetic gems in that the basic formula of the natural mineral is not adhered to closely in its synthesis. In natural spinel, the ratio of magnesium oxide to alumi-

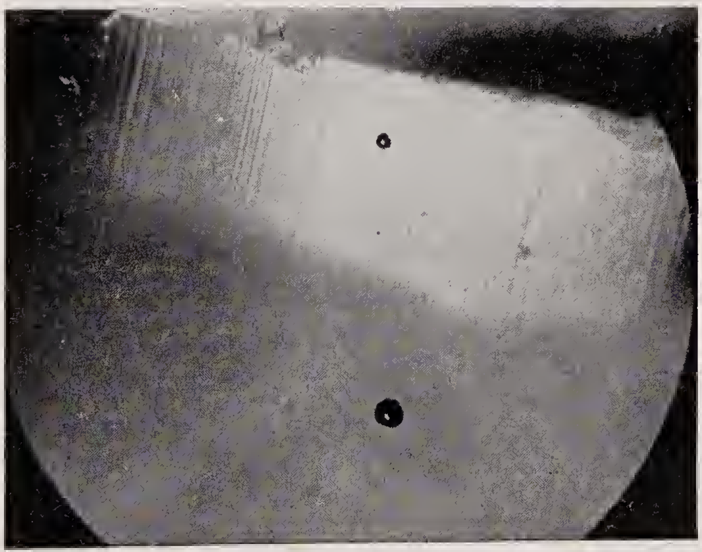


Photo by G.I.A.

Figure 88

Slightly angular gas bubbles in synthetic spinel.

num oxide is one to one. This is not true of the synthetic, which is usually made at a 3.5-to-1 ratio of alumina to magnesia. This ratio was determined largely by trial and error after the first spinel boules were formed accidentally when magnesium was added to the alumina in an effort to obtain an even distribution of the coloring agent to make more realistic synthetic blue sapphires. It was found that boules formed best at about the 3.5-to-1 ratio. The excess of alumina accounts for the slightly higher refractive index (about .01 higher than the usual 1.718 of the natural) and specific gravity of the synthetic. The specific gravity of the synthetic is about 3.64, compared to about 3.60 for natural spinel. The excess of alumina also accounts for the always-evident strong anomalous double refraction in synthetic spinel. The different patterns in the crossed

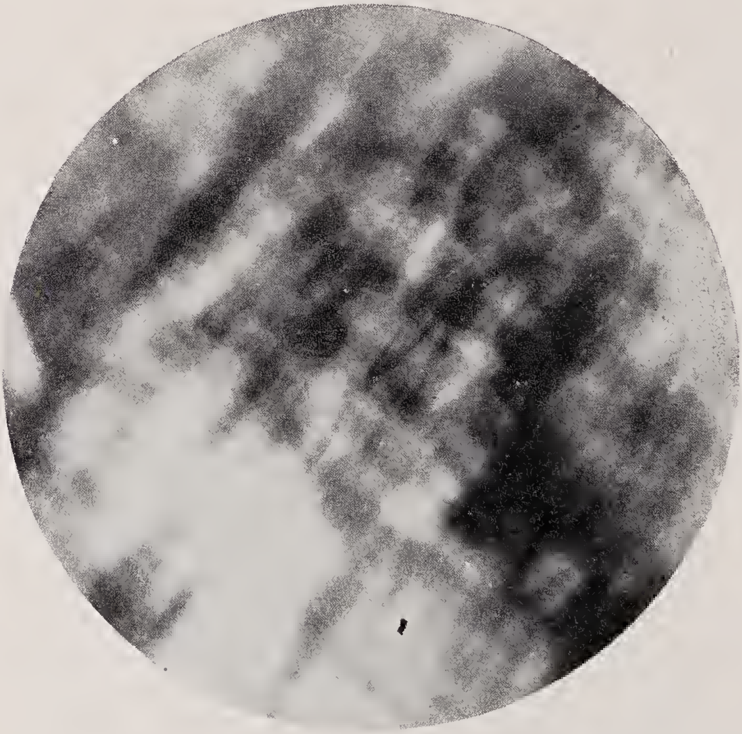


Photo by E. Gubelin

Figure 89

"Cross-hatched" appearance caused by anomalous double refraction in synthetic spinel 20X, under crossed Polaroids.

Polaroid position, as seen in the polariscope under about 5X, is characteristic. Typical patterns are shown under 20X in Figures 89 and 90.

Photo by E. Gubelin

Figure 90

Tourmaline-colored synthetic spinel with "fibrous" anomalous double refraction. 20X under crossed Polaroids.

Most of the production of synthetic spinel is in boules of transparent material. However, it is made in other forms as well. One is made by heating magnesium and aluminum oxides, plus a liberal amount of the cobalt oxide coloring agent, to a temperature slightly below spinel's melting point. The result is a coarsely crystalline sintered product resembling fine lapis-lazuli. It has a rich, violetish-blue color. In a remarkable reversal, real gold may be added to imitate the pyrite ("fool's gold") of the natural lapis-lazuli. The refractive index and hardness of synthetic spinel make it easily identified. Specific gravity is lower at 3.52.

A second form is made by reheating colorless material long enough for some of the alumina to separate, probably in the form of small corundum crystals. This imparts a cloudiness that gives rise to a realistic adularescent effect, making an excellent moonstone imitation.

In practice, synthetic spinel is much more likely to be confused with other gemstones in appearance than with natural spinel, for it is made in colors not encountered in the natural. Its rich, deep-blue color is a better imitation of fine sapphire than of blue spinel; in light blue and greenish blue it imitates aquamarine and zircon respectively; and in light and dark green, peridot and tourmaline respectively. By ordinary Verneuil methods, it was not made in red, except for very light tones resembling pink topaz or kunzite. However, about 1960, red synthetic-spinel caliber began to appear; this is Verneuil material. These small red stones have a refractive index of 1.725 and a specific gravity of 3.60. On one occasion a large man-made red spinel crystal grown on a platinum plate was examined in the Gemological Institute Laboratory in New York City; it varied from about 1.73 to over 1.75 in index.

Conclusive Identification of Synthetic and Natural Spinel.

Proof of *synthetic origin* is found in the presence of spherical gas bubbles. Gas filled spheres in synthetic spinel are usually smaller and much less numerous than in synthetic corundum. Curved striae are not found in synthetic spinel, except in the newly reported red varieties, but curved color bands may be seen rarely. Another type of inclusion characteristic of synthetic spinel is a "bread crumb" inclusion. Under dark-field illumination this type of inclusion appears as a bright porous spot that seems to have been caused by the coalescence of several small bubbles in close proximity. The presence of very strong anomalous double refraction is invariable in synthetic spinel. Its appearance in the polariscope, when the instrument is in its dark position, has been called "cross-hatched," i.e., alternately dark and light patches form a lattice-work pattern under

5X to 10X. (See Figures 89 and 90 for more highly magnified examples.) Natural spinel is rarely strained, and when it is, it does not show the lattice pattern. Strain double refraction in a natural spinel when visible in the polariscope is usually localized around an inclusion or group of inclusions.

Synthetic spinel is often flawless. A combination of the high 1.73 refractive index and the "cross-hatched" appearance in the polariscope constitutes proof of synthesis. An index of 1.718 (±.002) and no more than weak strain double refraction is typical of natural spinel.

The spectrum of synthetic blue spinel differs materially from the natural, as shown in the table of absorption spectra. This provides a sure means of distinguishing the synthetic from the natural.

Colorless synthetic spinel, a variety unknown in the natural, is a commonly used diamond imitation. It is readily distinguished from diamond by its 1.73 refractive index and very low relief when immersed in methylene iodide. Even in water, its relief is very low, compared to that of diamond. It fluoresces a bright greenish-white under short-wave ultra-violet.

Both the moonstone and lapis-lazuli imitations are easily distinguished from their natural counterparts by the higher index and specific gravity of synthetic spinel.

Spinel can be proved to have a natural origin by the presence of angular inclusions. The common inclusions in natural spinel are small octahedra of spinel, which may be scattered throughout the stone, or arranged in groups resembling the "fingerprint" inclusions in corundum.

Indications Suggesting Synthetic or Natural Spinel.

1. Signs of rapid polishing, such as striations on facets left by the lap and irregular cracks along facet edges, indicate synthetic material. Careful fashioning suggests natural spinel.

2. Dark blue synthetic spinel exhibits flashes of red as the stone is turned.

3. The color of synthetic spinel seldom bears any close re-

semblance to the colors found in natural spinel, since the natural gem is usually darker in color.

4. In many cases, ultra-violet radiation will actuate in synthetic spinel a fluorescence of a color never observed in similar colors of natural spinel. This is especially true of blue or green synthetic spinel which shows very strong red fluorescence under ultra-violet radiation, while blue or green natural spinel rarely exhibits such fluorescence.

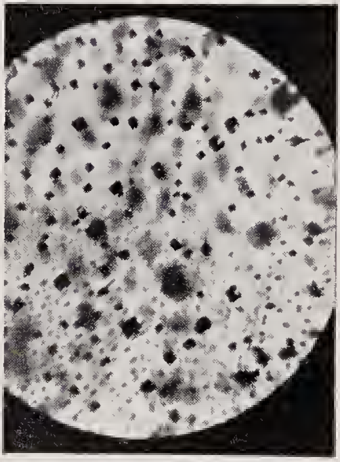


Figure 91

Numerous octahedral spinel crystals, which typify natural spinel.

Indications alone are insufficient to make an identification. No identification of synthetic or natural spinel should be made unless based on observation of characteristic inclusions, or a "cross-hatched" appearance in the dark position of a polariscope.

SYNTHETIC EMERALD

Beryl had been synthesized in the laboratory several times by earlier scientists, but the first commercial emerald production was accomplished by Carroll Chatham about 1940. I. G. Farben announced success in the synthesis of emerald in 1935, about the time Chatham claims to have produced his first crystals, but the German material was not marketed. Chatham's process, about which he maintains utmost secrecy, is obviously either a hydrothermal or flux-fusion process, not a Verneuil type. Chatham's synthetic emeralds resemble natural stones in that they have irregular liquid and

Photos by G.I.A.

Figure 92

Wisp-like pattern of liquid inclusions in synthetic emerald under 20X.

Figure 93

Synthetic emerald liquid inclusions under 100X.

Figure 94

Tiny tabular square crystals in Colombian Emerald.

gas inclusions, plus other angular enclosures such as colorless crystals, probably of phenakite, another beryllium silicate. A particularly significant feature is the prevalence of cubic crystals of platinum. This suggests the use of platinum as the liner of the autoclaves or other growth vessels. Although the early product was very limited in size, large crystals of over 1000 carats have been grown, and transparent cut stones of over five carats are available. Chatham synthetic emeralds have a distinctly bluish-green color not common in the natural emerald.

In 1961, the synthetic emerald-coated prefaceted natural beryl, made by Johann Lechleitner of Austria, was introduced by Linde Air Products Co., as "Linde Synthetic Emerald." Since the overgrowth is thin and the natural core colorless or nearly so, the coating is easily detected, although the properties of the overgrowth approximate average natural emerald figures, in contrast to the Chatham product.

How to Distinguish Synthetic from Natural Emeralds. Chatham synthetic emeralds are readily distinguished from natural stones. Despite the presence of natural-appearing inclusions, distinct differences in physical properties and other characteristics simplify the testing problems. The refractive indices of the Chatham product are 1.561-1.564 or 1.565, close to .01 below the lowest figure encountered in natural Colombian emerald. The specific gravity is only about 2.65 to 2.66, in contrast to the approximate 2.71 of natural Colombian material and the higher figures for other sources. A heavy liquid adjusted to the density of 2.67 serves to separate the Chatham synthetic from the natural, although a rare, heavily flawed natural stone may float with the synthetics, or a Chatham synthetic with an unusual number or size of platinum crystals may sink.

Synthetic emeralds fluoresce dull red under ultra-violet. The long-wave (3660Å) radiation is recommended. The fluorescence could best be described as weak to distinct in some cases, so it is important to make the test in a dark room, with the stone placed on a dull-black background. Very rarely, intense green natural emeralds exhibit a weak fluorescence, but it is a purplish red and does not seem to remove the stone's transparency, as does the fluorescent effect in Chatham synthetics.

Another difference between synthetic (Chatham) and natural emeralds is in transparency to short-wave ultra-violet. Natural emeralds are opaque to wave lengths below about 3000Å. If a short-wave ultra-violet lamp is placed over a stone covering a hole in an opaque shield, it is possible to determine whether radiation is transmitted or absorbed by the unknown by placing the mineral scheelite below the opening. If the specimen is transparent, the scheelite fluoresces a bright blue; if it absorbs the 2537Å radiation, there is no radiation to fluoresce the scheelite, so it remains dark. Chatham synthetic permits the scheelite to fluoresce, but the natural does not. This is best performed in a dark room.

If a double refractive emerald-green stone has three-phase inclusions; an index of 1.57 or higher and it sinks in 2.67 liquid; if it fails to fluoresce under long-wave ultra-violet; or if it is opaque to short-wave ultra-violet, it may be assumed to be natural. If it fluoresces under long-wave ultra-violet; is transparent to short wave, has wisp-like two-phase inclusions, has an index of 1.561-1.565 and floats in 2.67 liquid, it is Chatham synthetic emerald.

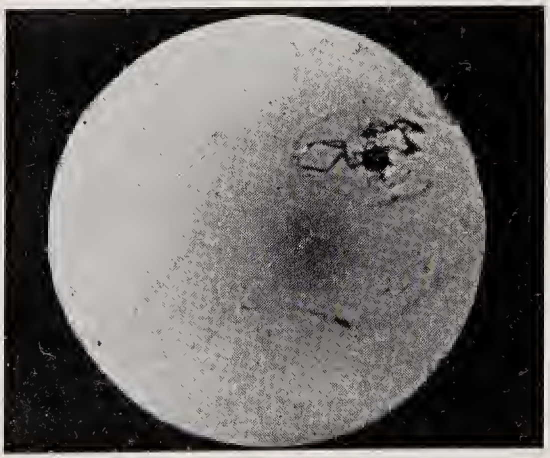


Figure 95

The diamond-shaped tabular crystal in this three-phase inclusion in an emerald indicates Russian origin.

Any test but fluorescence and specific gravity is conclusive, and these two together may be so regarded.

The so-called Linde Synthetic Emerald is characterized by the fact that the synthetic-emerald overgrowth is not polished on most facets, so the distinctive growth patterns are to be seen under magnification. If thicker coatings become the rule in the future, facets may be polished, but this product will still be easy to identify. Usually, the thin, intense green coating is noted under magnification, but, if not, it is obvious when the stone is immersed in water or bromoform. Property values are those of natural emerald. Inclusions are of types expected in other varieties of beryl, except for the thin synthetic layer. Here, the most prominent features are numerous thin, elongated cracks.

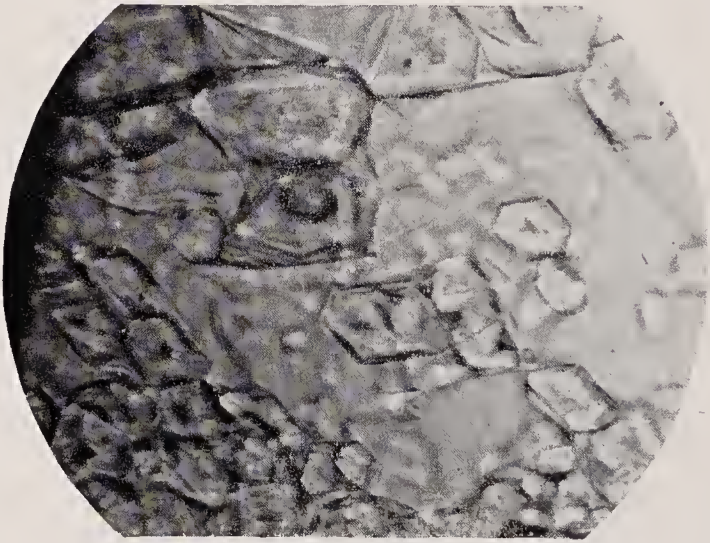


Photo by E. Gubelin

Figure 96

Plane of calcite inclusions in Colombian emerald.

Synthetic Rutile. Titanium oxide in the tetragonal structure of the mineral rutile has been produced since 1947 in boule form using the Verneuil process by the Titanium Division of the National Lead Co. In nature, rutile is opaque or nearly so, but the synthetic is made in a transparent form in very light yellow, light and dark blue, golden brown, brownish-red and green colors. For jewelry purposes. the nearly colorless light-yellow variety is by far the most commonly used.

The properties of rutile are unusual: its enormous dispersion and birefringence, together with its high refractivity, make for a spectacular appearance. The fire is unparalleled, but despite its higher indices, it is less brilliant than the singly refractive, highly transparent diamond. The refractive indices of synthetic rutile are 2.616-2.903, giving a birefringence of .287. Dispersion is approximately .330, B to G, compared to diamond's .044. The specific gravity is 4.26 and hardness about 6-6½.

Synthetic rutile is easily recognized by its tremendous fire and birefringence, its hazy transparency, and slightly yellowish color. Under magnification, the great doubling is apparent and spherical gas bubbles are often seen. This material has been sold under many names, such as "Titania," "Miridis," "Kenya Gem," "Titangem," and many others.

Strontium Titanate ("Fabulite"). Another Verneuil-process product, an oxide of strontium and titanium, is unique among synthetic gem materials, in that there is no natural counterpart. Sold under the trademarked name "Fabulite," it is perhaps the best imitation of diamond in appearance. It is singly refractive, has a refractive index of 2.409 and is transparent and colorless. Except for a much higher dispersion, the resemblance to diamond is close. However, hardness is only about 5-6. Specific gravity is 5.13. The high dispersion distinguishes it from diamond. Spherical gas bubbles are usually evident. Scratches caused by larger grains of abrasive are almost never entirely removed and odd rounded indentations and ridges are common.

Synthetic Diamond. The synthesis of diamond, first authenticated by General Electric in 1955, has since been duplicated in many other laboratories. General Electric is producing several million carats of synthetic diamond grit annually and De Beers is also in production. General Electric has produced crystals up to a carat size in the laboratory, but they are too weak structurally to be useful for industrial purposes as yet. Production of gem-quality synthetic diamonds may be achieved at any time, but it seems at this writing to be some time away.

Chapter XI

Doublets, Triplets, Foil Backs, and Imitations

Assembled Stones

Description. Doublets, triplets, and foil backs are commonly used substitutes for many valuable gems. The term *assembled stones,* used by Robert M. Shipley to include all three, will be used to designate these substitutes.

Doublets are made by joining two pieces of material with a colorless cement. In a garnet-and-glass doublet, the glass is usually fused to the garnet crown.

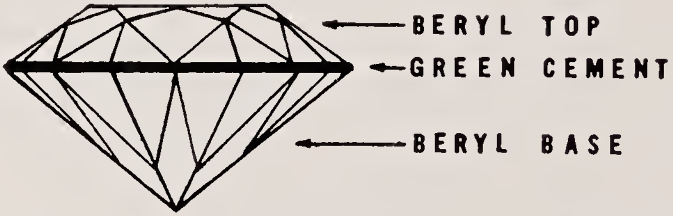


Figure 97

Genuine triplet.

Triplets are constructed by joining two pieces of material with a cement that gives the stone its color (Figure 97).

Foil backs are made by attaching a mirror-like back to the stone to enhance a star, or to give either brilliancy or color, or both.

Classification. Assembled stones are classified according to the proportion of genuine material in their makeup.

In a *genuine doublet or triplet* both gem portions of the stone are genuine material of the species which the stone imitates. A *genuine beryl triplet* is made by cementing two pieces of light colored beryl with an emerald-colored cement.

A *semi-genuine doublet or triplet* contains only one natural portion of the species it imitates. Colorless beryl, green cement, and colorless quartz were used to form a triplet once common to the jewelry trade.

A *false doublet, triplet, or foil back* contains one or more portions of natural material, but the final product does not represent the gem used in the genuine portion. If star quartz with a mirror base is made to represent star sapphire, the result is a false foil back. A garnet top, red glass-backed doublet made to represent ruby is a false doublet. Two pieces of quartz held by a green cement to lend an emerald color, form a false triplet.

Types of Assembled Stones Commonly Encountered. Since the appearance in the market of synthetic corundum and synthetic spinel, many of the assembled stones formerly used in quantity to represent the more valuable gems are no longer manufactured. Three varieties of assembled stones—the OPAL DOUBLET, EMERALD TRIPLET, and QUARTZ BACKED BY A MIRROR TO REPRESENT STAR SAPPHIRE—are now the most commonly encountered types of assembled stones. GARNET-AND-GLASS DOUBLETS in all colors; representing emerald, ruby, sapphire, aquamarine, and topaz, once produced in such large numbers, are still commonly seen. The garnet top is almost always almandite, but since the final product takes on the color of the glass back, the color range of this imitation is almost unlimited.

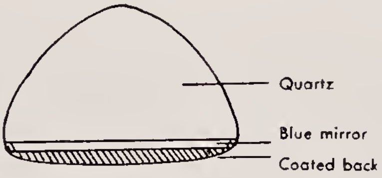


Figure 98
Star quartz foil back.

Natural star sapphire with a good star but a gray color may be made into a triplet with a blue cement. or a doublet with a blue sapphire or synthetic sapphire back. There are many other combinations and types of assembled stones. There are a variety of star imitations employing synthetic corundum with either an engraved flat base or with a lined mirror, to give the effect of the rutile inclusions of natural ruby and sapphire. Often, the back is cement or porcelain. but sometimes a second piece of synthetic corundum or, more rarely. low quality natural corundum is applied to the back. A common type of triplet is made with two pieces of colorless synthetic spinel or quartz joined by cement, permitting good color imitations of amethyst. topaz. emerald. sapphire. ruby and other gemstones. A patent has been applied for on a diamond imitation consisting of a "Fabulite" pavilion and a synthetic-sapphire crown. The sapphire serves both to decrease dispersion and to increase durability. Doublets of synthetic sapphire and synthetic rutile have also been made. Jadeite of a translucent white color has been fashioned into three pieces, allowing a gap to be filled with a green jelly-like substance. The result is an excellent copy of fine green jadeite. A practice common in the past but rarely seen today, except in old jewelry, was that of mounting pale stones in a completely enclosed setting with a color applied to the pavilion facets to improve the apparent quality greatly.

Detection of Doublets and Triplets. There are many tests which may be used for the detection of doublets and triplets. Probably the most effective is one which reduces the reflections from the facets, and enables the observer to examine the interior of the gem clearly.

Immersion is the best means of reducing facet reflections. The two pieces of a doublet, the plane or planes of separation between the stone portions, or the colored cement of a triplet are usually evident when the stone is immersed.

The red ring test is a very simple means of detecting a garnet-and-glass doublet if the stone is of a color other than red. If the stone is placed table down on a piece of white paper, a red ring close to the girdle, produced by the garnet crown, appears.

Under careful observation in reflected light even a novice may notice a distinct difference in luster between the portions of a garnet-and-glass doublet, with garnet revealing much higher luster than glass. In addition, since garnet caps on garnet-and-glass doublets seldom cover the whole crown (Figure 99), a division line is usually evident on the bezel facets.

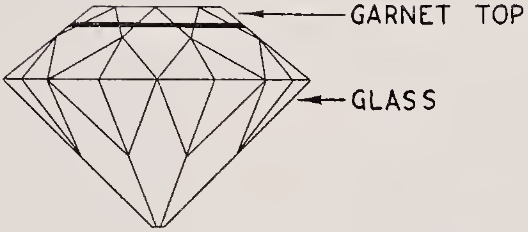


Figure 99
False doublet.

Refractive index readings, taken on the crown of the stone and on a back facet, may reveal a doublet or triplet by a large difference in the readings.

Fluorescence. When stones are placed under a radiation of 2537Å, the cement used in the colored layers of triplets often

Figure 100
Garnet-and-glass doublet under 30X. Note the sharp luster change on bezel facets.

fluoresces very strongly, while the tops and backs do not. Thus the cement layer stands out very clearly, establishing the nature of the assembled stone. The test is also effective for garnet-and-glass doublet detection. Because the glass back of a garnet-and-glass doublet usually fluoresces a greenish-yellow and the garnet top fails to fluoresce, the doublet's back surfaces appear to be covered with greenish-yellow powder, while only a dark spot is visible in the position of the garnet crown.

The most important use of the fluorescence test is for a rapid check on a large number of gems. No further tests would be necessary for those gems which fluoresced as described above. Since the cement layer of triplets and the glass in garnet-and-glass doublets sometimes do not react to ultra-violet radiation, failure to fluoresce in the manner described is not proof that an unknown gem is not a doublet or triplet.

Magnification may resolve the separation plane of a doublet or triplet. Often simple observation directed parallel to the girdle of the stone shows a difference in color between the two portions.

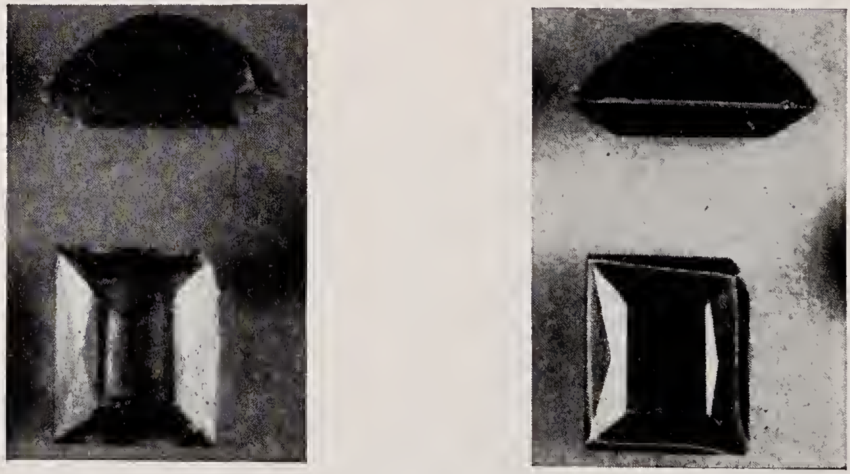


Figure 101

Triplet in ordinary light. *Triplet under 2500Å radiation.*

Detection of Foil Backs. Foil backs are detected more easily than other imitations — the presence of the foil is difficult to conceal. Faceted gems that have foil covering the back facets are unmistakable. Star quartz is backed by a foil mirror to enhance the star and to lend a color similar to star sapphire or ruby. Most star imitations using mirror backs are apparent immediately from the unnatural appearance of the back. Imitations tend to be much too transparent to have been able to produce a star. The star appears to reflect from the back to a point opposite the light source, in contrast to the seeming appearance of a natural star at the surface. Sometimes rough synthetic or natural corundum is used as a backing, giving the imitation a deceptively natural look. If the stone is mounted, the joining plane may be concealed, adding to the difficulty of detection. In rare instances, it may be necessary to remove such a stone from its mounting to identify it; however, it is usually detected from above.

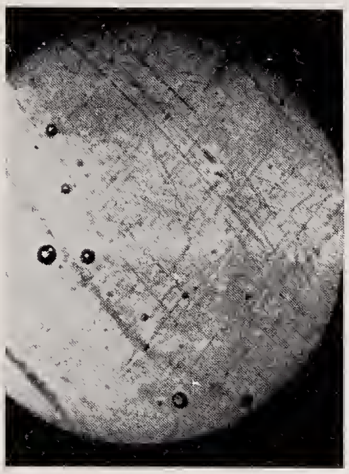


Figure 102

Garnet-and-glass doublet showing both "silk" and spherical gas bubbles.

Figure 103

Garnet-and-glass doublet showing the separation plane distinctly.

Color-coated pale rubies, sapphires and emeralds show too little dichroism for their depth of color. They also have weaker spectra than their depth of color suggests. This condition is seldom encountered except on gemstones mounted with their pavilions concealed.

One form of deception that is easily misjudged is that in which what appears to be a large diamond is only a thin-crown—without pavilion. The portion below the girdle is entirely concealed by a closed-back gypsy-style mounting. (See Chapter XXIII.)

Imitations

The classification *imitation* includes all noncrystalline materials which are wholly produced by an artificial process in an attempt to imitate genuine stones in appearance.

Imitations Commonly Encountered. The imitations most commonly encountered are *glass, imitation foil backs* (glass fashioned as gems, then backed by foil), *plastics*, and *imitation pearl*. By far the most important imitation is *glass* or *paste*.

Photo by G.I.A.

Figure 104

Swirl-marks or flow lines with spherical bubbles in glass.

Glass. Glass imitations vary from molded stones used in the cheapest costume jewelry to types which, through skillful manufacturing methods, very closely imitate the gems they represent. The natural gems which glass best imitates are chalcedonic quartz, beryl (emerald and aquamarine), jade, turquoise, and topaz. It is less effective in imitations of corundum, diamond, and zircon.

Glass used in imitation of gemstones is composed of silicon oxide (the composition of quartz) combined principally with an alkali, such as calcium, sodium, or potassium, or with lead, boron, thallium, aluminum, or barium oxides, depending upon the properties desired. Imitations vary from silica glass, which is almost entirely silica, to strass glass, which contains less than forty percent silica and more than fifty percent lead oxide. The addition of lead oxide considerably increases the refractive index, specific gravity and fire of the glass.

The range of colors which can be produced in glass is almost unlimited, and the colors achieved often very closely approach the colors of the natural gems the glass represents. Gold chloride is used in glass that most nearly reproduces the color of ruby. Yellow glass is produced by the addition of silver oxide or chloride and antimony. Impure carbon is sometimes added to glass with manganese to produce a golden yellow, while cobalt oxide is used to produce blue. Glass backed by a lined foil is used as an imitation star.

Detection of Glass. The variation in quality of glass used to imitate gemstones is such that some types may be identified at a glance while others may be detected only after a series of careful tests.

A distinctive vitreous or glassy luster on fracture surfaces is sometimes sufficient proof of a glass imitation of an opaque gemstone. Glass imitations of turquoise and chalcedony are easily detected by the glassy luster of fracture surfaces.

A feeling of warmth in the stone as it is held in the hand is an indication of glass. In contrast, a natural or synthetic crystalline material (a better conductor of heat than glass because of its crystal structure) is cool to the touch.

A molded appearance of the back facets is easily detected in the cheaper varieties of glass imitations which are polished only on the crown. Facet junctions in molded glass are not as sharp as they would be in polished materials. The facet surfaces are not flat, but usually have a slight depression at the center .

Too much fire for the natural gem may be noted in glass imitations of corundum, emerald and topaz, as well as other gems of low dispersion.

Too little dispersion marks a glass imitation of diamond or zircon.

The action of a drop of water may distinguish glass. Place a small drop of water on the stone's surface with a toothpick or a match stick. On glass or any amorphous gem material the drop will spread, while on crystalline material the drop will retain its shape. The stone must be scrupulously clean.

The usual glass imitation has either *spherical bubbles* or *elongated bubbles* similar to those of viscous liquid which is being stirred.

Glass often shows characteristic *flow* lines, so named because they resemble light effects on viscous flowing liquids, such as molasses. These may have been caused by improper mixture of the materials which comprised the glass melt, or by disturbance of the melt as it cooled. In some instances, insoluble material of

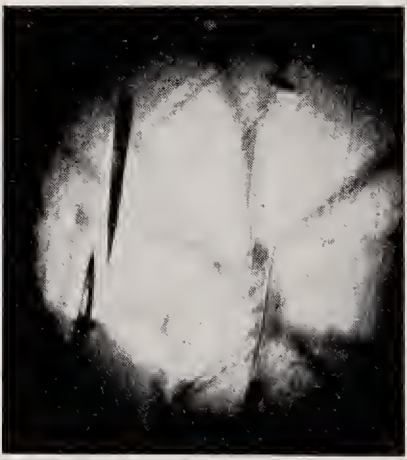


Figure 105
Swirl-marks and greatly elongated gas bubbles in molded glass.

an angular nature is added to the melt to simulate inclusions characteristic of genuine gems. Such inclusions are invariably accompanied by numerous spherical and elongated gas bubbles.

Irregular curved color lines often serve to distinguish glass imitations of nontransparent gemstones such as turquoise and jade.

Occasionally glass appears to be *free of inclusions,* even under magnifications of 100 power or more.

The *refractive index and specific gravity* of a glass imitation are rarely close to the readings of the gem imitated in color.

Glass, an amorphous substance, *is singly refractive.* It may occasionally be strained enough to show an anomalous double refraction, but rarely as strong as that of synthetic spinel. A glass imitation of a natural, singly refractive gemstone will never have both the same refractive index and the same specific gravity as that of the genuine, though it may have one or the other.

A glass imitation of a natural, doubly refractive gemstone may have approximately the same refractive index and the same specific gravity as the gemstone it imitates (quartz, beryl or topaz), in which case the singly refracting character of the glass will identify it. Nontransparent glass imitations through which some light passes at the edges especially those which are rough on the back, may give a reaction in the polariscope similar to that characteristic of doubly refractive crystalline aggregates. Vitreous luster on tiny fractures on the rough surface, or bubbles visible near the surface, identify such imitations.

Glass used for gem imitations has a normal refractive index range from 1.48 to 1.70, and its specific gravity may be as low as 2.2 and as high as 4.2. Since refractometer hemispheres with indices near 1.95 are made of glass, 1.70 obviously is not the extreme limit. However, glass above 1.70 is too soft to wear well and tends to develop a surface film quickly. While two glass imitations of topaz have been reported with an index of 1.77, glass imitations above 1.70 in refractive index are rare indeed. If the refractive index is above 1.70, the specific gravity is above 4.2, with refractometer glass over 6.0.

The hardness test can be used whenever tests have proceeded to the point at which the only remaining possibilities are glass and some other singly refractive gem other than opal.

The hardness of glass is usually 5½ or less. Some types of glass usually blue or green, may be 6 in hardness, though most of the lead glasses used in gem imitations are softer than window glass. A steel file will scratch even the harder glasses.

Plastics. Plastic gem imitations, long used to imitate amber, ivory and opaque gem materials, are finding increasing use in a transparent form for costume jewelry.

Detection. Plastic imitations are easily identified by their low specific gravity and hardness. All of the common plastics used as gem imitations have specific gravities below 1.59, the density of Carbona. Heat, preferably in the form of an electrically heated needle, causes a plastic to give off a characteristic acrid odor. A properties table for plastics follows:

	R. I.	S. G.
Plexiglass and lucite	1.50	1.18 (±.01)
Bakelite	1.61 (±.09)	1.25-1.55
Polystyrene	1.63 (±.04)	1.05

NOTE: In the event fillers are used in opaque plastic gem imitations, much higher specific gravities are possible.

Pearl imitations are described in Chapter XII.

Hemetine* is a substitute manufactured to resemble hematite. It is a sintered product in which various materials have been used from time to time. Galena, lead sulphide was an early raw material, lending the product a heavy (near 7.0) specific gravity and a black streak. Recent material is said to contain mainly iron and titanium oxides, giving a red-brown streak, and nearly the same specific gravity and hardness as hematite. For identification see hematite above.

The specific gravity varies from about 4.0 to 7.0 and the hardness from 2.5 to 6.

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*Trademark.

Chapter XII

Pearls, Cultured Pearls, and Imitations

The pearl, so unlike other gemstones in appearance and origin, requires special methods of determination. Since the cultured pearl was first introduced into the jewelry trade, the most difficult determination facing the jeweler has been the distinction between natural and cultured pearls. While natural and cultured pearls are easily distinguished from imitations, their separation from one another is exceedingly difficult.

The difficulty encountered in the distinction between the pearl and its reproduction is due to the similarity of the nature of cultured pearl to natural pearl.

Natural Pearl. Pearl is formed within a mollusc which deposits a substance called NACRE around an irritant that has found its way into the organism. The irritant may be a microscopic grain of foreign matter such as sand, or possibly a disease or parasitic growth suffered by the mollusc. Often no identifiable source of irritation is found when a natural pearl is sectioned. When the irritant finds its way into the mantle of the animal, NACRE is added layer by layer. NACRE is formed by a web-like deposit of conchiolin (a bone-like material) the spaces between which are filled with tiny crystals of aragonite (the orthorhombic form of calcium carbonate) which are oriented with the long direction perpendicular to the layer. In other words, the tiny crystals are arranged radially about the pearl. (This structure is shown in Figure 106.) Salt-water pearls of gem quality are produced almost entirely by species of the mollusc genus *Pinctada* (also known as *Meleagrina* and *Margaritifera*). Fresh-water pearls are produced by various clam and mussel genuses.

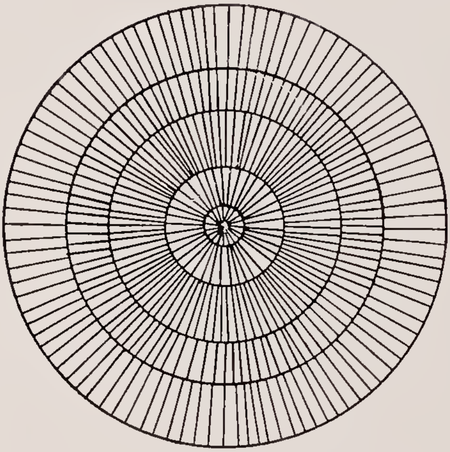

Figure 106

Schematic cross section diagram of a natural pearl.

Cultured Pearl. Salt-water pearls are cultured by introducing a mother-of-pearl bead and a piece of mantle tissue into a channel cut most often into the foot of the mollusc, *Pinctada Martensii.* Sometimes, a second incision is made and another bead is inserted; when this is done, the channel is cut in another portion of the visceral mass. In Japanese water, the rate of nacre accumulation is slow; the cultured pearl removed from the mollusc, usually three and one-half years later, is only about one millimeter larger in

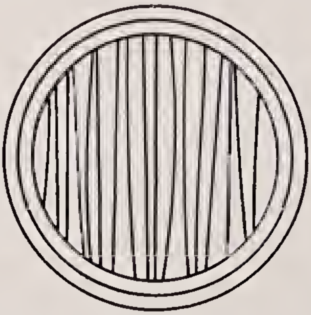

Figure 107

Cross section diagram of a typical cultured pearl.

diameter than the mother-of-pearl bead. Australian and other tropical pearling stations produce much larger cultured pearls, because of a much more rapid nacre accumulation. Whereas the largest cultured pearls produced in Japanese waters are only about ten millimeters in diameter, sizes in excess of fifteen millimeters are produced in Australia and elsewhere.

Lake Biwa, a large reservoir on the main island of Japan (Honshu) is the site of several pearl-culturing farms employing the fresh-water clam. *Hyropsis Schlegeli.* The major difference between the fresh-water and salt-water methods are the production of many pearls per mollusc and the absence of solid nuclei in the fresh-water production. The mantle is notched in a number of places and a small piece of mantle tissue inserted into each incision. In each, a pearl sac forms and a baroque pearl grows. After about three years, the mollusc is brought to the surface and the pearls are carefully removed. The product is typically white, of good luster, and about 6 x 3 millimeters in size. The mollusc is then returned to the lake and a second crop grows in the same sacs. The second harvest, several years later, is less baroque, but still rarely spherieal. A small percentage is almost spherical, and satisfactory for use in necklaces.

Nacreless Concretions. Spherical and button concretions with out nacre are formed in many bi-valved molluscs. Frequently seen are those from the Cherrystone clam. These coneretions, without nacre, are usually dark purplish-brown. Nacreless pearls have little or no value.

Conch Pearls. Light orangy-red or pink concretions formed within the conch often are called "pink pearls" although they are not nacreous. They are characterized by a mottled surface appearance that gives the impression of a regular pattern of tiny reflecting surfaces (somewhat similar to the appearance of amazonite).

The Distinction Between Natural and Cultured Pearls. Since the surface material of natural and cultured pearl is the same, having been deposited by a pearl-bearing mollusc, it is difficult to arrive at a positive identification of an undrilled pearl. There are many jewelers who claim the ability to distinguish between cultured and natural pearls on sight. Their methods are usually based on the difference in appearance between pearls from Japanese molluscs and those from the molluscs from other sources. It is true that Japanese pearls are more likely to have a greenish body color than other pearls. However, of the men who have dealt with pearls for a lifetime, few are willing to depend upon visual examination in a decision that will make a difference of thousands of dollars in the valuation of a necklace. Too often. mistakes result from any other test than a scientific one. Of the several tests described on the following pages, only three can be regarded as conclusive. The reaction of a natural pearl in the double-mirror method is proof of its identity. The X-ray diffraction method is also reliable. The combined X-radiographic and X-ray fluorescence methods are reliable. The other tests described serve only as indications in the identification of natural or cultured pearls.

Simple Pearl Tests

Specific Gravity. The large mother-of-pearl bead that forms the core of a cultured pearl is usually fashioned from the shells of fresh water bi-valves. The fresh water shell commonly used has a greater specific gravity than natural pearl. If a solution of the correct density is prepared, by far the larger proportion of natural and cultured pearls may be accurately separated. To prepare such a solution, dilute pure bromoform (obtainable in an alcohol solution at almost any chemical supply house) with grain alcohol or acetylene tetrabromide until Iceland Spar (calcite) is suspended. A few more drops of bromoform are added to just bring the calcite to the surface.

Caution. Bromoform is usually sold in an alcohol solution that has a density of about 2.5, instead of 2.9, the density of the pure material. To wash out the alcohol, pour the bromoform into water (alcohol and water are miscible, but bromoform, and water are not) and decant the water carefully several times to bring the bromoform to its pure state.

In the solution prepared by the dilution of pure bromoform in the manner described, natural pearls will usually float, and cultured pearls normally sink. Eighty per cent of natural salt water pearls will float in a solution with a density of 2.713, and ninety per cent of cultured pearls will sink.[1]

Candling. A second simple test which often gives indefinite results, but which is helpful in the identification of a complete pearl strand, is candling. Candling requires the intense illumination of the pearl, preferably in a darkened room.

In the cultured pearl, the parallel layers of a prominent mother-of-pearl core can be seen as lines across the pearl. The test is not reliable since some cultured pearls fail to show stripes, and cracks in a natural pearl can cause a striped appearance in intense illumination. Candling of the normal natural pearl shows only a decrease of light transmission from periphery to center.

To candle a pearl effectively, an intense — but well shielded light source is essential. An opaque shield should completely cover the light except for an opening about one millimeter over which the pearl is placed. It is necessary to turn the pearl slowly in the light beam to find the "stripes" in a cultured pearl or to be certain that such a structure is not visible. While candling is unreliable in the testing of a single pearl, it furnishes an indication as to the identity of a strand.

Magnification. A test often used by jewelers because of its ease of application is magnification of the walls of the drill hole of a pearl with a loupe or microscope. The brown conchiolin separation layer is often visible between the mother-of-pearl core and the layers of nacre. Care must be taken to light the drill hole adequately so that the brown layer is visible, if present. Unfortunately, while the presence of such a layer is a good indication of cultured pearl, it is not proof, since similar phenomena occur in natural pearls and are not always present in the cultured pearls. In addition, the concentric layers expected in a

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[1] Anderson, B. W.; Payne, C., GEMMOLOGIST, May, 1939.

natural pearl may be evident when the nacre around the core of a cultured pearl is thick.

Appearance. The "gelatinous" appearance and the greenish body color is a good indication of Japanese pearl, and, thus of cultured pearl. Before World War II, however, cultured pearls were produced in the East Indies, where the external nacre characteristics were unlike those of the Japanese product. Still, to the experienced pearl man, the Japanese characteristics are good indications of cultured pearl even though the lack of such characteristics is no longer truly indicative of natural pearls. Black welts, not common in natural pearls, have long been considered suggestive of cultured origin. The insertion of a large mother-of-pearl bead sickens the mollusc, which accelerates conchiolin production, producing the welts.

More Conclusive Pearl Tests

Pearl Endoscope and Pearloscope. The pearl Endoscope and the Pearloscope are efficient and exact instruments for the determination of the origin of drilled pearls. There are several methods of identification that utilize metal needles with mirrors polished at 45° angles to their length, principal ones being the single mirror method and the double mirror method described below. All of them may be applied with the Endoscope and the Pearloscope. The Pearloscope has an efficient pearl candler in addition to the features of the Endoscope. The needle is mounted in a vertical position on the Pearloscope in contrast to the horizontal needle on the Endoscope. All endoscopic methods share the serious shortcomings of requiring individual examinations, so necklaces must be cut apart and only fully drilled pearls may be tested.

Single Mirror Methods. There are two single mirror methods. The First is used to examine the walls of the drill hole by directing an intense light source at the pearl from the side. After passing through the pearl to the mirror the light is reflected to a microscope focused on the mirror. This allows the

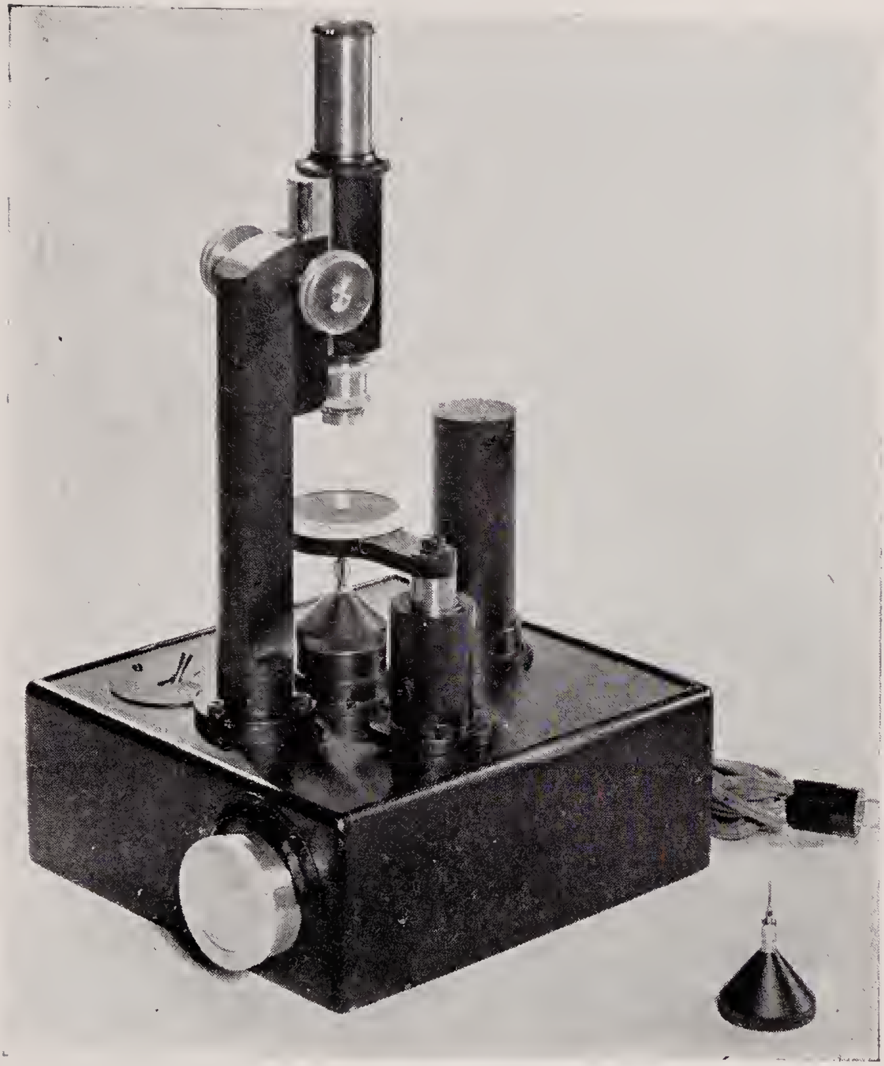

Figure 108
The G.I.A. Pearloscope for drilled pearl identification.

microscopist to examine the walls of the drill hole. In a natural pearl the observer can see the concentric rings layer after layer to the center of the pearl, accompanied by a gradual decrease in the light intensity. In the examination of a cultured pearl, the rings end abruptly as the mother-of-pearl core starts, and the light decreases sharply.

The second single mirror method, much less conclusive, is essentially the opposite of the first method. In place of being used to examine the walls of the drill hole, the mirror is used to direct intense illumination against the walls, with the observation being directed from the side of the pearl without magnification. If the pearl has a mother-of-pearl core, the intense light is carried by repeated reflection along the parallel layers of the mother-of-pearl up to the nacre rings, where it gives an effect similar to chatoyancy (the "cat's-eye" effect). This effect is seen only in the cultured pearl, but not all cultured pearls show the phenomenon distinctly. Natural pearl, which retains the light within the inner rings by reflection, has an even illumination in contrast to cultured pearl.

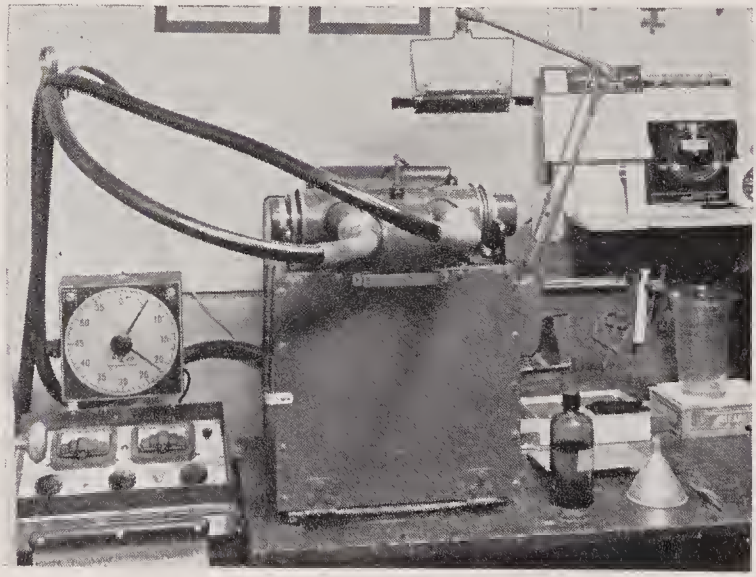

Figure 109

X-ray Pearl Testing Unit.

The Double Mirror Method. The double mirror method employs a hollow needle which has two mirrors inclined at 45° to the length of the needle and at 90° to each other. When carefully used this test is almost 100 per cent effective. One pearl in thousands fails to lend itself to positive identification. The hollow needle is mounted before an intense light source so that the light is directed through the needle to the first mirror surface from which it reflects to the wall of the drill hole. If the pearl is cultured, the light will be carried along between the parallel layers until it passes through the thin nacre ring. If the pearl is natural, the effect is different. A microscope is directed through the end of the drill hole opposite to the needle end, and directed upon the second mirror. When the light strikes the walls of the drill hole in a natural pearl, it is carried around the pearl within the ring of nacre it first strikes by total reflection, much in the manner that light is carried from end to end of a curved lucite rod. The light carried within the concentric ring strikes the second mirror and is reflected as a bright flash to the microscope and to the eye of the observer. Although this method will, on very rare occasions give indefinite results. it is never inaccurate when a positive flash is observed.[1]

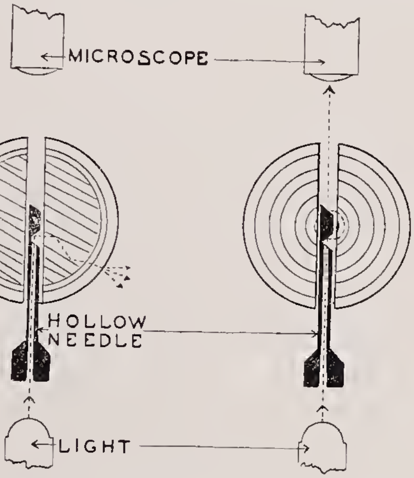

Figure 110

Left. Schematic diagram of the reaction of a cultured pearl in the double mirror testing method of the endoscope or pearloscope.
Right. Reaction of a natural pearl.

X-RAY METHODS

The various X-ray methods will not be described in

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[1] Anderson & Payne—ibid.

detail for such equipment is not easily available and is too expensive for the usual gemological laboratory. However, many jewelers send pearls to laboratories for identification by X-ray, so some mention of the basis for such tests should be included here.

X-ray Diffraction. Prismatic crystals of aragonite are arranged radially around the center of the pearl with their length at right angles to the surface. (See Figure 106.) In the cultured pearl, the prismatic crystals are also perpendicular to the layers, but the layers in the core are straight and parallel, not spherical and concentric as in the natural pearl. Only the thin outer covering of nacre has the same arrangement as natural pearl. (See Figure 107.) When the natural pearl is placed in the path of the X-ray beam, with the beam passing through the center of the pearl, the rays are traveling parallel to the length of the crystals. Because of the atomic arrangement of aragonite, the resulting diffraction pattern will have a six-fold symmetry (what appears to be an hexagonal pattern of spots.) (See Figure 111.) The only direction in which the cultured pearl can give a similar pattern is in the one position (±37°),[1] where the parallel crystals of the mother-of-pearl core are parallel to the X-ray beam. To avoid this unlikely chance, it is safest to take a second X-ray photo after rotating the pearl 90°, if the first pattern shows a hex-

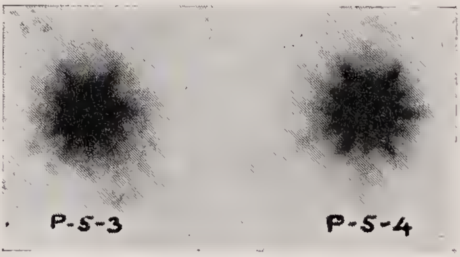

Figure 111

Hexagonal diffraction patterns from natural pearls.

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[1] See Barnes, William H., "Pearl Identification by X-ray Diffraction," Gems and Gemology, vol. V, 1947, pp. 508-512.

agonal pattern. If the cultured pearl is in any other position this will give a pattern with four-fold symmetry. (See Figure 112.) The X-ray diffraction method has important weaknesses. Pearl necklaces to be tested must be cut apart and tested individually or in small groups. It is reliable for the detection of Japanese salt-water cultured pearls with thin nacreous shells, but large cultured pearls with nacre of significant thickness in relation to the mother-of-pearl bead would give hexagonal patterns in most directions. X-ray diffraction likewise is of no value in the detection of fresh-water pearls cultured without nuclei, for there is no structural difference between them and natural pearls. Radiography is more satisfactory and reliable.

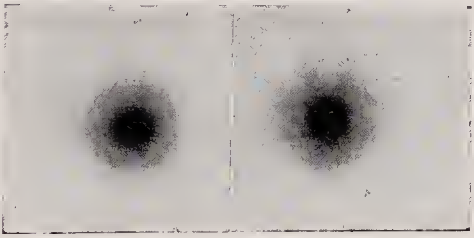


Figure 112

Four-fold symmetry in cultured pearl diffraction pattern.

Radiographic Method. The X-radiographic method of pearl identification permits the examination of an entire strand of pearls at one time. In contrast to the narrow pencil of X-radiation required for the diffraction photograph, radiography employs a broad X-ray beam. Pearls to be tested rest in a container, transparent to X-rays, placed over suitable film. Radiography as employed in the pearl testing laboratory is comparable to that used by the dentist to study teeth. This method depends upon the difference in transparency to X-rays of the conchiolin layer around the mother-of-pearl core and the nacre coating of the cultured pearl. In a natural pearl the absorption of X-rays is dependent on thickness, since it is a homogeneous object. The resulting radiograph may exhibit several fine gradations in X-ray transmission in the natural pearl, while the cultured pearl usually shows a very definite dividing line at the separation between core and nacre, due to the extreme transparency of the conchiolin layer about the mother-of-pearl core.

Detection of Artificial Color in Black Pearls. Artificial coloration to produce black pearls is a rather common practice, but the methods used are carefully guarded secrets. If a pearl is dipped into a black dye, the dye may be detected by rubbing a white swab soaked in a weak solution of nitric acid against the pearl; the swab will be slightly discolored. Others are soaked in a solution of a silver salt, such as silver nitrate, and exposed to light to precipitate free silver. These show white streaks on an X-radiograph, due to silver's opacity to X-rays. Others seem to be treated in a manner that attacks the conchiolin and turns it black. Acid swabs fail to detect such treatment. Black pearls with a natural color usually fluoresce in a pink to red color under long-wave ultra-violet, in contrast to treated blacks, which either fail to fluoresce or have a whitish fluorescence. A few natural blacks fail to fluoresce, but these are distinguished by the presence of green, rod-like inclusions in a near-transparent surface layer. Otherwise, failure to fluoresce in a reddish color is satisfactory evidence of artificial color. Black pearls that fluoresce red also have characteristic absorption spectra. (See the table of spectra in Chapter XIII.)

Fluorescence. In some cases, radiography alone provides insufficient evidence for positive results. However, with the same equipment employed in pearl radiography, the characteristic reactions of pearls to the exceedingly short-waved X-radiation, were determined by A. E. Alexander, Ph. D. All cultured pearls utilizing fresh-water shell cores glow when exposed to the X-ray beam. Since no salt-water shell cores have been encountered to date, all cultured pearls (with the exception of the exceedingly rare experimental cultured pearls with glass cores) fluoresce before the X-radiation. Of the natural pearls, only fresh-water pearls and some Australian pearls fluoresce. The information obtained from this test added to that provided by careful study of the radiograph permits reliable determinations on strands and single pearls alike.

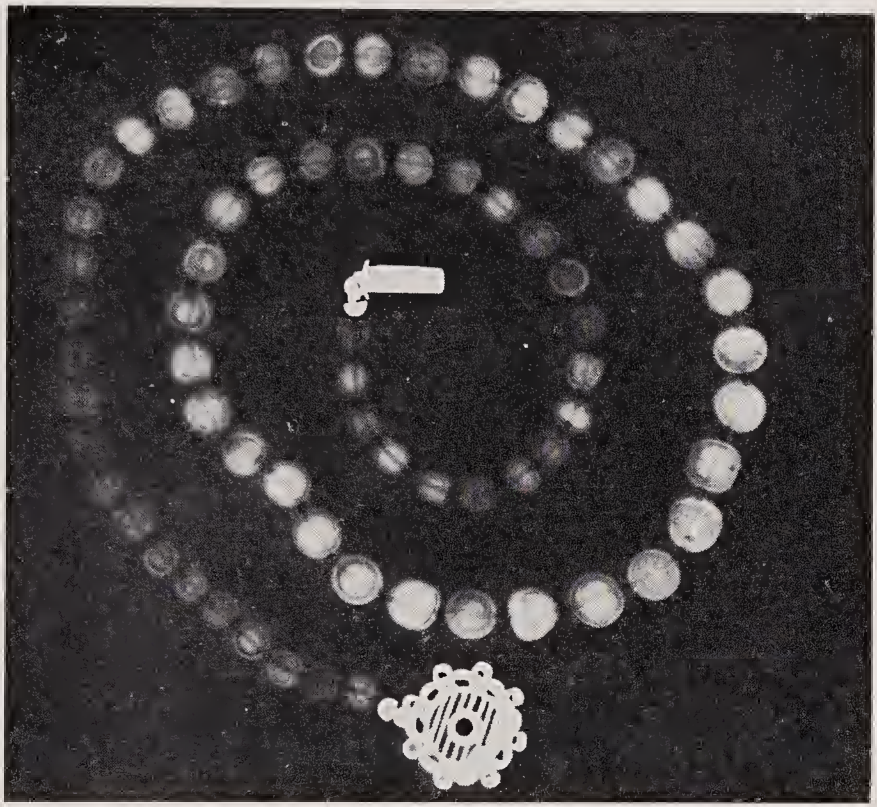


Figure 113
X-radiograph of a strand of natural pearls.

Pearl Imitations

Much improvement has been made recently in the appearance of pearl imitations marketed extensively in the United States. The imitation pearl is usually one of two types; wax-filled glass spheres, or solid glass spheres. Both are given a pearl-like luster by dipping the spheres into "essence d'orient," a suspension of guanine (the tiny lustrous crystals of which are removed from the membrane coating of fish scales in an aqueous detergent) in cellulose nitrate. "Essence d'orient" provides luster but the imitations must be dipped into clear cellulose acetate and then clear cellulose nitrate to achieve an interference effect similar to orient.

Such imitations are remarkably similar to natural pearls in appearance.

Wax-filled Imitations. Careful examination of the drill hole will show the character of wax-filled imitations. The edges of the hole have a glassy character — a vitreous luster — and a rougher appearance than the natural or cultured pearl. Wax-filled imitation pearls are smooth to the teeth in contrast to the gritty character of genuine nacre. A needle inserted into the drill hole at an angle will reveal the soft wax by feel. A pinpoint pushed against a wax-filled imitation will cause a momentary depression in the surface in contrast to natural pearl or any other substitute. Caution: Although the vast majority of wax-filled imitation pearls feel smooth to the cutting edges of the teeth, recently a few with gritty material added to the essence d'orient have been encountered in the Gem Trade Laboratory in New York City. Both solid glass and wax-filled imitations fail to react to a droplet of hydrochloric acid, in contrast to the rapid effervescence noted in the droplet on cultured or natural pearls.

Solid Imitations. Solid glass imitations (so-called "indestructible pearl") are quite common in the trade. Their quality, like that of the wax-filled imitation, depends upon the number of applications of the "essence d'orient". Often as many as forty applications are made in the finer qualities. The detection of the solid glass imitation is similar to that of the wax-filled. It, too, is smooth to the teeth. The edges of the drill hole are glassy. Under magnification, the surface appears smooth, rather than scaly as in genuine and cultured pearls. When held to the light, both genuine and cultured pearls show a translucent rim not visible in the imitation.

Pink Coral. Pink conch pearls are often imitated by the use of coral. They have a higher specific gravity than coral (conch pearl about 2.85, coral 2.70), and their surface appearance is different. Coral shows distinct irregular surface pits. Conch pearls often have a mottled appearance.

Conclusions. One of the most difficult tasks for the practicing gemologist is the distinction between genuine and cultured pearls. Unless the jeweler has a Pearloscope or X-ray equipment, he can do no more than make simple tests which will give him an indication, but not final proof, of the true nature of the pearl. The gemologist with limited equipment is more often forced to submit pearls to trade laboratories for identification than any other type of gem.

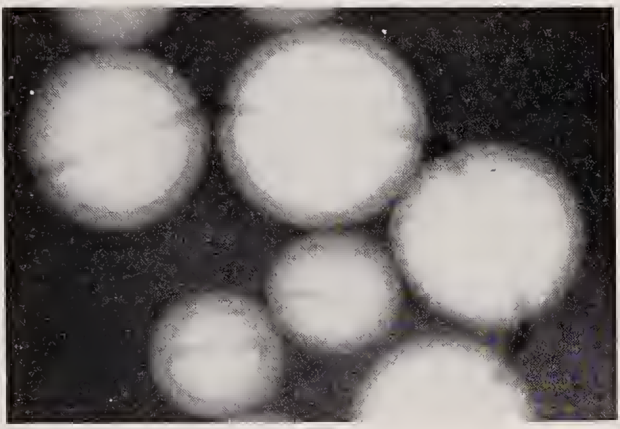


Figure 114

X-radiograph of a strand of cultured pearls.

Figure 114 b

A radiograph of fresh-water cultured pearls from Lake Biwa. Japan

Chapter XIII

The Spectroscope

The value of the spectroscope in gem identification continues to increase as new substitutes are introduced. The beauty of a distinctive absorption spectrum has always made the use of the spectroscope a test of particular interest to gemologists; but, for many years, it could be said that the spectroscope, although a valuable weapon in the gemologist's arsenal, was not one of the absolutely essential instruments. Today, there are separations that cannot be made by gemologists without the spectroscope. For example, diamonds given a yellow or brown color by subatomic-particle radiation in a nuclear reactor, followed by heat treatment, are indistinguishable from naturally colored yellow and brown diamonds, except by spectroscope. It also serves to separate naturally colored green jadeite from dyed jadeite and jadeite triplets, as well as some colors of natural from synthetic corundum, which may be difficult to identify beyond argument by other means. It is useful for identifying gem rough quickly and often for testing either mounted or loose goods more quickly than would be possible otherwise. Just as the utility of the refractometer is reduced by its inability to give readings for highly refractive gems or from rough surfaces, so is the utility of the spectroscope less than universal. However, it is often of greatest value where the refractometer is useless.

The industrial scientist who utilizes spectroscopy usually heats the unknown material to white heat or renders it incandescent between carbon electrodes in an arc. However, since such tests are obviously impractical in the spectroscopic analysis of gemstones, neither method is useful for the gemologist, who must rely on absorption spectroscopy when testing gemstones. He analyzes light which passes through or is reflected from the gemstone. Thus, absorption spectroscopy offers a practical test in gem identification, in that the stone is not harmed in any way. Since the color of a transparent gemstone is the result of selective absorption, it is reasonable to expect that white light transmitted through a colored material may show bands or lines of absorption when examined by an instrument constructed to show a spectrum of the light transmitted through or reflected from the stone.

Types of Spectroscopes. For the purpose of the gemologist, simple, inexpensive instruments are satisfactory. The two major types are prism spectroscopes and diffraction spectroscopes. The diffraction type has the advantage of being inexpensive and showing an even spectrum in contrast to the prism type, but it passes much less light. Although the prism type widens the violet end of the spectrum and shortens the red, its greater light transmission makes it a much more useful spectroscope, since sufficient light is more important than the relative spreading of the spectrum. The simplest instruments show a single spectrum for the gem

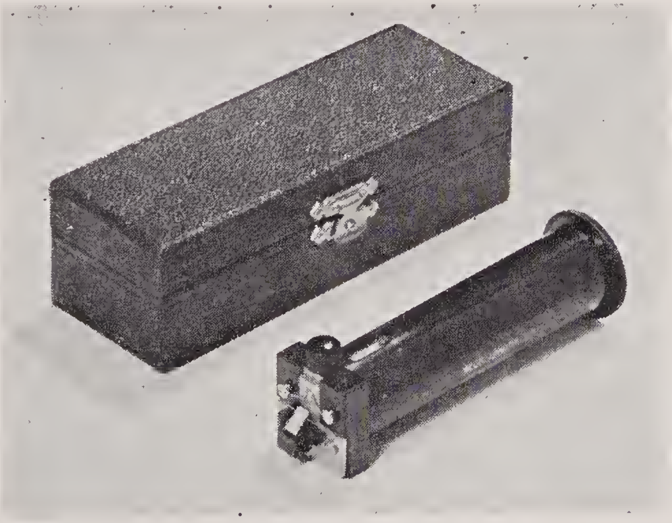


Figure 115
Beck Hand Spectroscope

being examined. However, there are fairly inexpensive spectroscopes available which utilize light from another source to illuminate a graduated and numbered scale for comparison purposes. Perhaps the simplest and least expensive type of the prism instruments is the Beck Hand Spectroscope, model number 2458, which is made in England. Beck makes a number of other spectroscopes and spectrometers. Perhaps the most practical is their model 2522, with a built-in wave-length scale. Although parallax makes it all but impossible to achieve great accuracy with it, it does assist the user to gain a close approximation of the position of a line. Other manufacturers, such as Rayner and Zeiss, also make hand spectroscopes. Some hand spectroscopes do not allow absorption lines in the deep blue to be analyzed.

Testing a Stone. The key to the successful use of a spectroscope is effective lighting. It is essential to have the stone intensely illuminated in a manner that will permit only the light transmitted or reflected from the stone to be analyzed. One very simple means is to use the illuminator of a Diamondscope or Gemolite with the baffle removed and the iris diaphragm closed down so that the stone rests over the small opening which is left. The spectroscope is then placed so that the slit end is about one inch from the stone and in a beam of light transmitted through the stone. There are many other ways to illuminate the stone. Often a powerful source is required to provide enough light transmission through a dark stone. For this purpose, a slide or movie projector of 250 to 1000 watts is useful. If no projector is available, a projection lamp may be shielded and its light concentrated on the stone by a lens or a water-filled, flat- or round-bottomed, essentially spherical chemical flask. Light passing through a faceted stone is concentrated in small brilliant beams making the use of a hand spectroscope more difficult; therefore, magnification of such a beam into an even glow is advantageous. This may be accomplished by a hollow cylinder with a low-power magnifier at the end near the stone or, more conveniently, by using an ordinary microscope with the eyepiece removed. Most novice spectroscopists are plagued by the same problems. The light source used is too weak, the slit through which light enters the instrument is left too wide, and the instrument is not held with a steadiness that permits results to be studied. There is also a tendency to permit too much extraneous light to flood the slit, and, finally, the initial results are expected to resemble India-ink lines on white paper, instead of the often faint differences in absorption that occur.

For best results, the slit should first be closed and then opened only enough to make the full spectrum visible and to eliminate the strong horizontal lines across the spectrum. If the lines persist, a sharpened wooden match or toothpick may be used to clean the slit. If reflected light is used, the stone should be placed on a small pedestal over a dull-black background. The light beam should be focused on the stone or passed through a small opening near the stone, so that the only light falling on the slit is that which has passed through or, in case of opaque stones like turquoise, been reflected from the stone. The spectroscope should be mounted so that it may be moved freely until a satisfactory position is reached, when it should be possible to set it in that position. It is difficult to use a hand spectroscope, unless it can be held in a steady position. There are stands made to hold the Beck instruments, or a chemical supply house can furnish a post and a test-tube clamp to mount on it to hold the spectroscope.

Most hand spectroscopes are focused by extending or shortening the drawtube to sharpen the portion of the spectrum being studied.

Spectroscope Unit. To achieve fully satisfactory results, spectroscopic equipment needs both a high intensity, cool illumination, and flexibility for transmitted or reflected light. The late Lester B. Benson, Jr., designed a very practical unit meeting these requirements. This instrument, shown in Figure 119, employs a Beck wave length spectroscope with a variable-intensity concentrated light source. A right angle prism cools the beam, so that the specimen is not raised in temperature unduly during a prolonged examination. The spectroscope is mounted on a movable arm and the lamp on a folding mount. This combination permits a wide range of light intensities, using either transmitted light or light reflected at any angle from the surface or internally.

Agents Causing Absorption. Absorption of a portion of the white light entering a transparent gemstone, or reflected from an opaque one, is responsible for the color perceived. Unfortunately, the absorption is not sufficiently confined in wave-length to be characteristic for each color of each colored stone. Some metallic-oxide coloring agents are much more likely to impart a characteristic pattern in any substance in which they appear than are others. Among the coloring agents, chromium is a particularly prolific producer of characteristic spectra. It is responsible for the color of ruby, synthetic ruby, red spinel, emerald, alexandrite, pink topaz, green jadeite and demantoid, among other stones. A glance at this list shows that chromium oxide causes both the richest reds and the richest green colors. The reason for this is apparent in the spectroscope, since, in contrast to iron, which also produces red and green colors in gemstones, the chromium absorption is sharply defined: and in the wave-lengths between absorption lines or bands, absorption is minimal. Chromium causes slightly different spectra in each gem in which it appears, but, in general, it is responsible for broad absorption in the violet and in the center (green or yellow), and for narrow lines in the red portion of the spectrum. Some of the red absorption lines in transmitted light are often fluorescent lines in scattered light. Sometimes, there are sharp lines in the blue, as in ruby and synthetic ruby.

Iron, a strong coloring agent, both in ferrous and ferric forms, is responsible, or partially responsible, for the color in blue, green and yellow sapphire; almandite; yellow and green chrysoberyl; yellow orthoclase; peridot; green tourmaline; aquamarine; blue spinel; and other gems. Usually, iron is responsible for broad absorption bands in the blue and green portions of the spectrum. The absorption in diamond is not caused by impurities but by so-called color centers, which are defects in the lattice, with electrons occupying spaces between their ordinary positions.

One element that causes sharp spectral lines without being a prominent cause of color is uranium. Its most common appearance is in the type of zircon with the many sharp absorption lines. Such lines may even be seen in colorless zircon, showing that the uranium may permit such a high degree of transmission of such a well-distributed portion of the spectrum that the eye still perceives the stone as colorless.

Manganese is responsible for the flesh-red colors of rhodochrosite, rhodonite and some pink tourmaline; its usual characteristic in a spectrum is broad absorption in the violet and the blue. The rare earths, neodymium and praseodymium, usually present together, are responsible for several sharp bands in the yellow portion of the yellow apatite spectrum; they may be present also in other colors of apatite. Cobalt, which is used to impart a sapphire-blue color to synthetic spinel and glass, has a characteristic spectrum consisting of three strong lines in the blue-green, yellow, and orange.

Evaluating Results. The spectra reproduced herein are reasonably self-explanatory and need little, if any, further comment. The stars show rather well their dependability. Unless a distinct spectrum is seen, it is better for the novice to more or less disregard his findings. In other words, although some gems, such as ruby and synthetic ruby, always show a clear-cut spectrum (and failure to see that characteristic spectrum makes a ruby identification immediately suspect), there are many more cases when it is difficult for a novice to be sure that the vague absorption he detects is dependable.

The usual tendency for the beginner is to expect too much at first glance. Practice first on synthetic ruby, dark-blue synthetic spinel and almandite. Later, zircon, emerald and yellow diamond should be attempted. Lighting that will permit resolution of the lines in a natural yellow diamond should be adequate for most purposes. Caution: some yellow diamonds, especially richly colored so-called canary diamonds show no absorption lines.

In general, where a spectrum is marked with three stars, failure to find it in the gemstone makes an identification highly questionable. On the other hand, in two-starred and one-starred spectra, the failure to resolve a satisfactory spectrum is not of too great concern. In some cases, it will be necessary to examine a stone carefully in several directions under different conditions before it can be assumed that there is no characteristic spectrum to be seen. Treated diamond is an excellent example. There are times when the characteristic lines are very difficult to find; this is particularly likely when the stone being examined is permitted to take the full heat of an intense light beam. The treated diamond may not show the 5920Å line after the beam has heated it to a high temperature; therefore, the light should be passed through a water flask or prism or the stone held on an ice- or dry-ice-filled container.

The Visible Spectrum.

Red	7000 to 6400Å
Orange	6400 to 5950Å
Yellow	5950 to 5750Å
Green	5750 to 5000Å
Blue	5000 to 4400Å
Violet	4400 to 4000Å

Some of the characteristic spectra of the important gemstones are described in the following paragraphs. These and others are portrayed in the tables that follow.

Almandite Garnet. Ferrous iron causes a highly diagnostic spectrum in almandite. This is true despite a wide variation in appearance between the spectra of groups of almandites because of the variable iron content. Dark almandites show a very strong band in the blue-green and weaker bands in the green and yellow. Weaker absorption lines may be visible in the orange and one to several in the blue. In most almandites the blue-green absorption is strongest, but the other two major lines more nearly approach it in strength.

Beryl. Emerald shows a chromium spectrum with twin lines at 6835 and 6805Å, plus lines at 6620 and 6460Å. There may be lines at 6370Å and in deep-green stones at 4770Å. A rather vague absorption is seen in the yellow and yellow-green, centered near 6050Å.

Chrysoberyl. The yellow variety shows a broad band centered at about 4450Å in the blue-violet. The alexandrite variety shows a chromium spectrum. There is a strong doublet at 6805 and 6785Å.

A line usually is seen at 6450 and others at 6550 and 6650Å. There is a broad, fairly weak band in the yellow and lines in the blue at about 4750 and 4680Å.

Demantoid Garnet. Usually, demantoid shows a very strong absorption band in the violet, below about 4500Å. This usually seems to foreshorten the visible spectrum. Exceptionally rich, deep green stones show a doublet at the extreme red end near 7000Å and sometimes two weak bands in the red-orange and orange.

Diamond. In yellow diamonds usually a number of lines are visible in the blue and violet. The strongest of these is at 4155Å in the deep violet. Others are usually visible at 4530Å, a weak one at 4660 and 4780Å. Natural brown stones with a green fluorescence have a very weak 4980, a slightly stronger 5040, and a thin faint line at 5330Å. Based on a small number of observations it appears that natural green stones (for which no spectrum is shown) have a strong 5040 and a very faint 4980. The characteristics of irradiated diamonds are shown in the table in this chapter and discussed under diamond in Chapter XV.

Jadeite. Rich-green jadeite always shows three step-like lines in the red at 6300, between 6500 and 6600, and near 6900Å. They seem successively darker in steps to the upper limits of visibility. If the green color is intense, the strong, sharp 4370Å line, so valuable in the identification of most jadeite, may be masked by general absorption in the blue. For the characteristics of dyed jadeite, see the table in this chapter and the section on jadeite in Chapter XV.

Peridot. The peridot spectrum, caused by ferrous iron, gives three fairly broad bands in the blue area, centered at about 4960, 4740, and 4530Å.

Pyrope Garnet. The spectroscope provides an excellent means of separating the rare, nearly pure pyrope from dark-red spinel with a comparable refractive index. Each has a broad absorption band in midspectrum but that of pyrope is centered in the yellow-green at about 5750Å, whereas spinel's band is centered in the green near 5400Å. The band centered at 5050Å, characteristic of almandite, is often seen in pyrope also. Narrow chromium lines in the red may be seen on occasion.

Ruby and Synthetic Ruby. Ruby has a distinctive and dependable spectrum, caused by chromium. The synthetic has the same spectrum. There is a broad absorption band from about 6200 to 5400Å, which, with three clear lines in the blue at 4765, 4750, and 4685Å, and two lines close together at 6942 and 6928Å in the red, distinguish ruby. The lines in the red often appear as fluorescent lines; they are so close together that they usually appear as a single band with a hand instrument.

Sapphire and Synthetic Sapphire. (See Chapter X.)

Spinel. Red spinel, colored by chromium, has a wide band from about 5950 to 4900Å. There may be five or more thin fluorescent lines in the red, which are seen best by scattered light.

Blue spinel is colored by ferrous iron. The spectrum includes a band at 6320Å in the orange, bands at 5920Å in the yellow, 5550Å in the green, one at 4800Å, and a broad one centered near 4600Å in the blue. These bands and lines may be difficult to resolve.

Synthetic Spinel. The dark blue synthetic spinel shows a cobalt spectrum with three strong absorption bands. The two heaviest are in the orange, and yellow, with a slightly narrow band at about 5400Å in the green. Typical spectra for other colors of synthetic spinel are shown in the tables.

Tourmaline. Green tourmaline absorbs the red to 6400Å and shows a narrow band near 4975Å, a ferrous iron spectrum.

Red tourmaline shows an absorption line at 4500Å that varies with depth of color and the direction of light transmission. In deeply colored stones another slightly weaker line is seen at 4580Å. General absorption in the green is accompanied by a narrow line toward the yellow near 5300Å.

Zircon. The many representations of zircon spectra published in articles and texts are likely to be misleading because zircons showing the many lined, uranium-caused spectrum are exceptional. Most zircons show a line at 6535Å and a weaker one at 6590A. If weak, they are best seen by reflected rather than transmitted light. Green zircons always show a number of lines, usually more diffused than those of high property zircons. Yellow and brown Ceylon types and green zircons from Burma are most likely to show the many lined spectra that are shown in the tables.

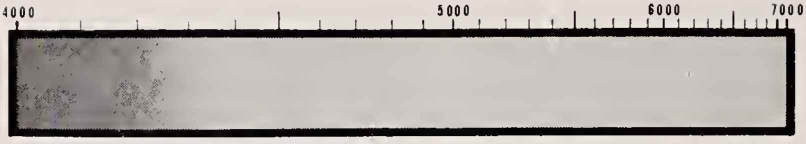
Table of Typical Absorption Spectra. The following reproductions were prepared by Robert Crowningshield, Director of the Institute's New York Trade Laboratory, to duplicate as nearly as possible the appearance of the absorption spectra of these materials. Crowningshield's technique produces particularly realistic reproductions of the appearances encountered by the gemologist using a prism spectroscope.

Most of the spectra are evaluated by one, two or three stars, in a system adapted from that used by B. W. Anderson. In this system, the following meanings are indicated:

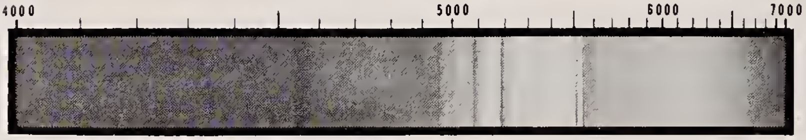
*** Always present and diagnostic in this color.
** Diagnostic when present, but not always present or clearly defined.
* Sometimes useful as a confirmatory test, if present.

If no star is used, the spectrum represents one that has been recorded in either of the GIA's laboratories, but either it is rarely seen or too few stones have been examined to be able to indicate value in testing. Some two- and three-star spectra represent very few stones examined in rare species or colors, but the presence of certain essential coloring agents that cause characteristic absorption makes for a safe assumption of diagnostic value.

Absorption Spectra of Important Gemstones

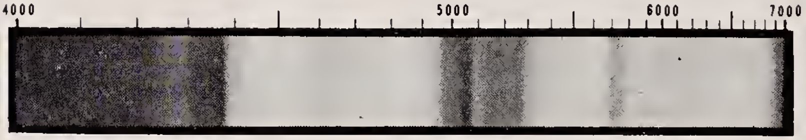


Andalusite — ordinary brown-green type ★



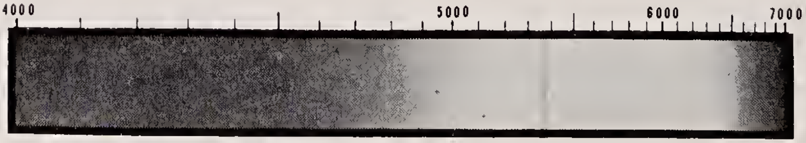
Andalusite — green (rare-earth spectrum) ★

Almandite — dark color ★ ★ ★



Almandite-Rhodolite — light color ★

Beryl — dark-blue aquamarine ★ ★



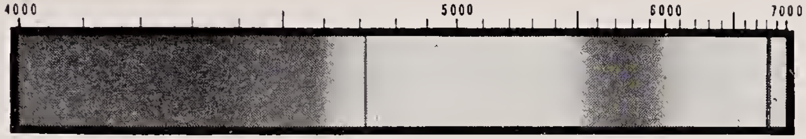
Beryl — common yellow-green ★ ★

|—— VIOLET ——| V B |— BLUE ——| B G |— GREEN | YG | Y | O | RED —|

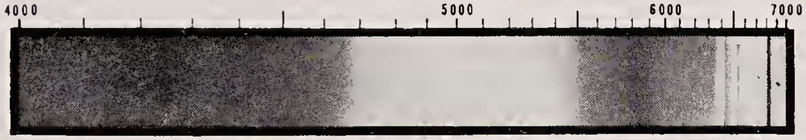
Absorption Spectra of Important Gemstones

Beryl — pale Brazilian pegmatite emerald (random orientation, scattered light) ✶

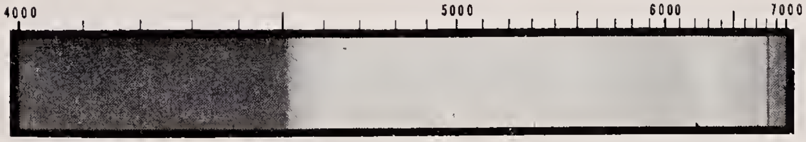
Chalcedony – dyed green ✶ ✶ ✶



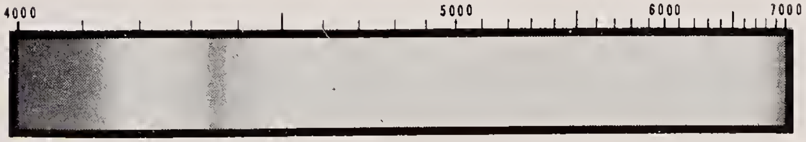
Chrysoberyl — alexandrite (red, or fast, ray) ✶ ✶ ✶



Chrysoberyl — alexandrite (green, or slow, ray) ✶ ✶ ✶

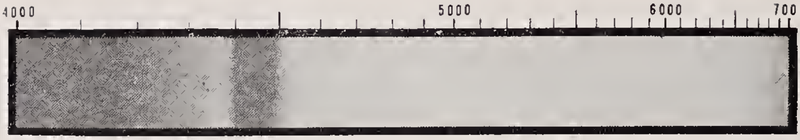


Chrysoberyl — alexandrite (weak color change) ✶

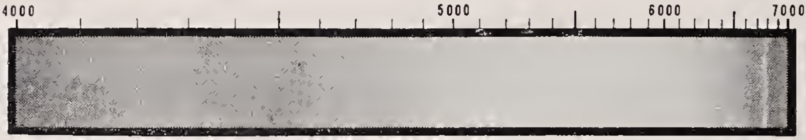


Chrysoberyl — pale yellow ✶ ✶ ✶

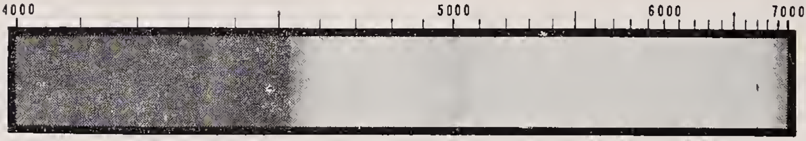
Absorption Spectra of Important Gemstones



Chrysoberyl — intense yellow-green ✶ ✶ ✶

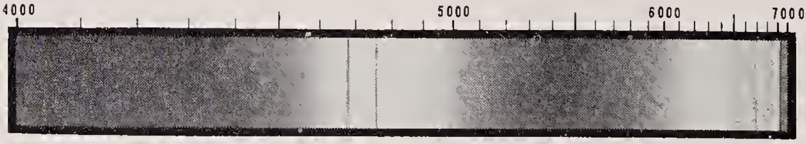


Chrysoberyl — rare, very light-green stone



Chrysoberyl — rich brown ✶ ✶

Corundum — Ruby and synthetic ruby, purple sapphire and dark padparadscha (direct transmitted light) ✶ ✶ ✶



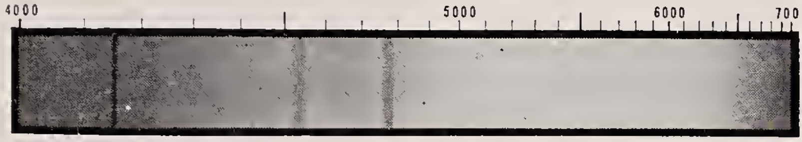
Corundum — ruby and synthetic ruby, purple sapphire and dark padparadscha (scattered light) ✶ ✶ ✶

Demantoid — ordinary yellowish green ✶ ✶ ✶

|—— VIOLET ——|— VB —|—— BLUE ——|— BG —|— GREEN —|— YG —|— Y —|— O —|— RED —|

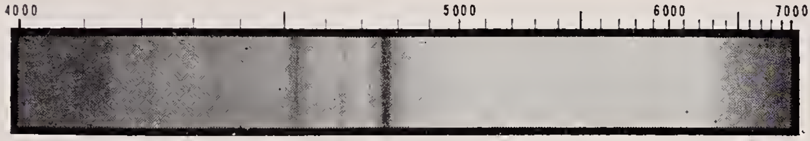
Absorption Spectra of Important Gemstones

Demantoid — very rich green * * *

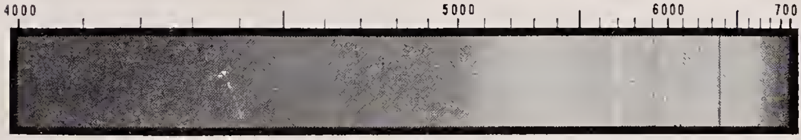


Diamond — pale yellow (cape spectrum) * *

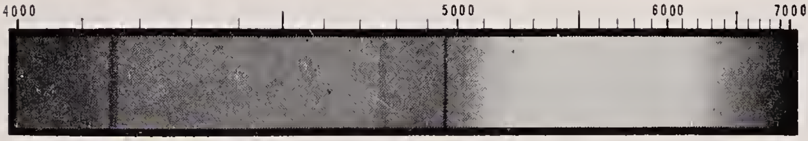
Diamond — brown (shows green in transmitted light) *



Diamond — intense yellow (rich cape) * *



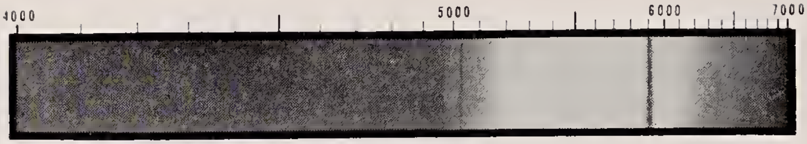
Diamond — treated pink (orange fluorescence). Line at 5700 Å is a fluorescent line * * *



Diamond — treated yellow, yellow-green, light brown and some blue (maximum transmitted light) * * *

|—— VIOLET ——| VB |—— BLUE ——| BG |— GREEN —| YG | Y | O |— RED —|

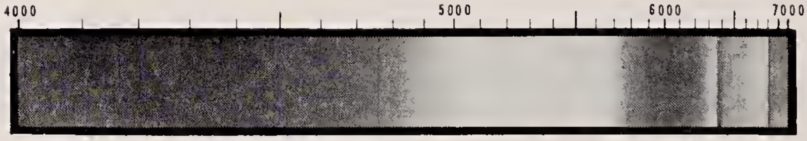
Absorption Spectra of Important Gemstones



Diamond treated yellow-brown, yellow, black, if any light can be transmitted (diffused transmitted light) ✶ ✶ ✶

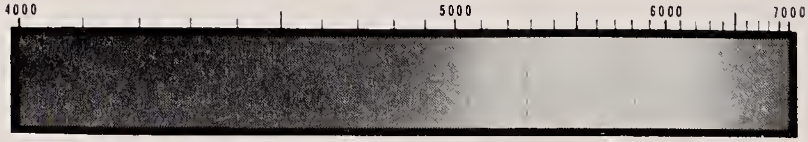
Emerald — medium green (random orientation) ✶ ✶ ✶

Emerald – synthetic and natural (optic-axis direction) ✶ ✶ ✶



Emerald – synthetic and natural (ordinary ray) ✶ ✶ ✶

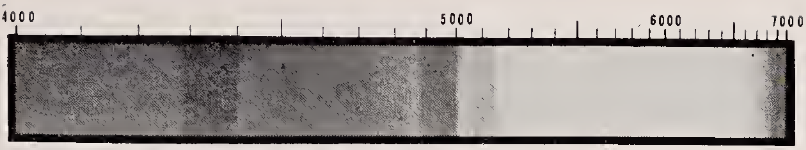
Emerald synthetic and natural (extraordinary ray) ✶ ✶ ✶



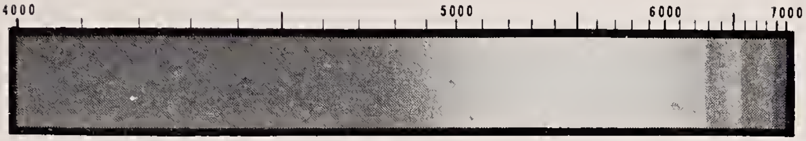
Grossularite yellow-green from Mexico (rare-earth spectrum) ✶

|— — VIOLET ——| VB |—— BLUE ——| BG |— GREEN | YG | Y | O |— RED —|

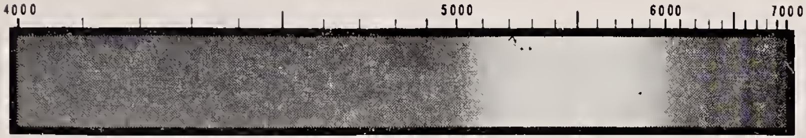
Absorption Spectra of Important Gemstones



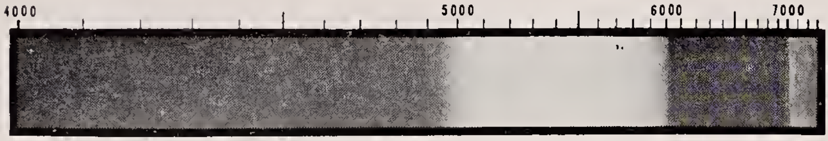
Hessonite — (rarely this pronounced; often not visible) ✶



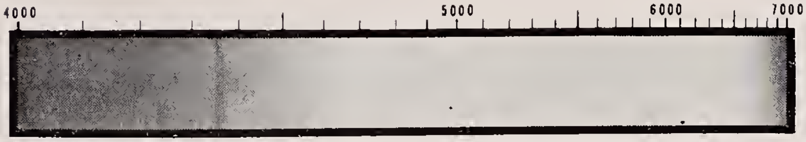
Jadeite — intense emerald green ✶ ✶



Jadeite — very dark green ✶ ✶



Jadeite — very dark green "Yunnan" jade. Thin edge, strong transmitted light



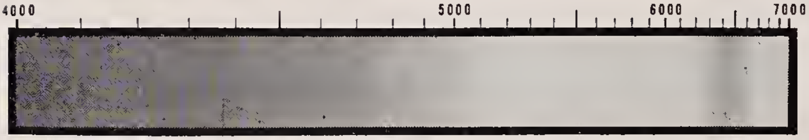
Jadeite — any translucent color except green ✶ ✶

Jadeite — medium chrome green ✶ ✶

|—— VIOLET ——| VB |—— BLUE ——| BG |— GREEN | YG | Y | O | RED —

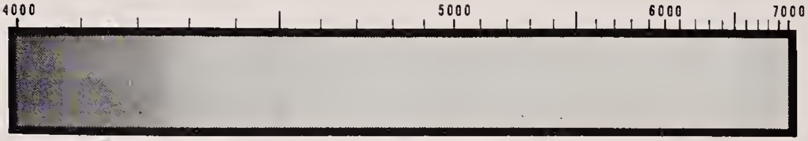
Absorption Spectra of Important Gemstones

Jadeite and serpentine — intense dyed green ✶ ✶



Jadeite — dyed green (faded to light green to greenish blue) ✶ ✶

Nephrite — intense green (thin pieces, transmitted light only) ✶



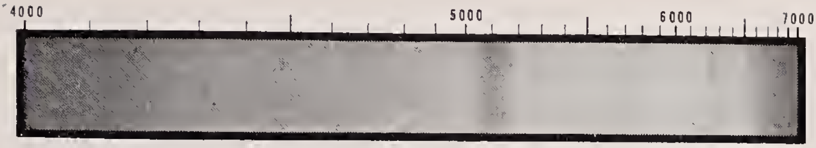
Orthoclase — yellow ✶ ★

Pearl — red-brown to black conchiolin from shell edge of *Pinctada Martensii*

Pearl — red-brown to black conchiolin from shell edge of black pearl-bearing mollusc (species undetermined)

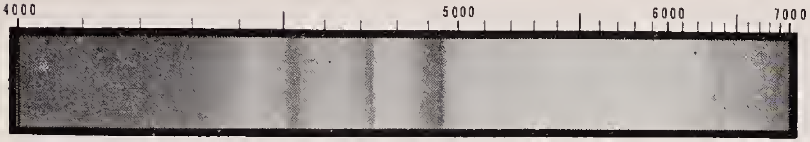
|—— VIOLET ——| VB |—— BLUE ——| BG |— GREEN | YG | Y | O | RED —|

Absorption Spectra of Important Gemstones

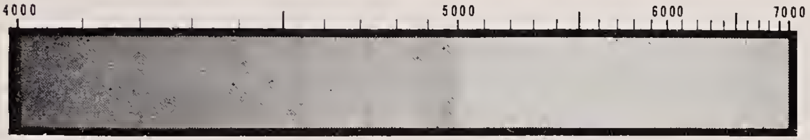


Pearl — light-gray to black pearls showing pink fluorescence (through which powerful beam is visible)

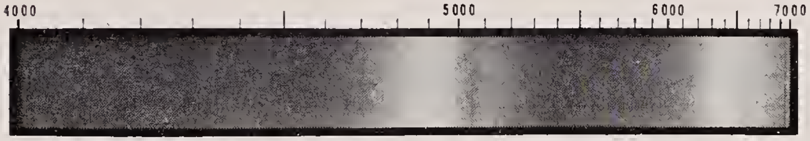
Pearl — red-fluorescent black pearls (specimens that transmit only a small amount of brownish-red light at the edges) ✶ ✶



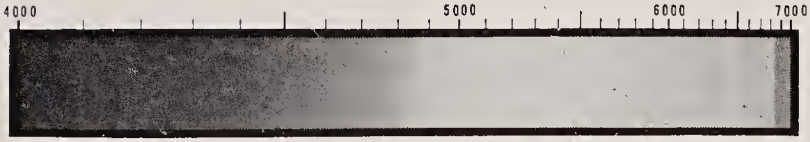
Peridot — large or very dark-colored stones ✶ ✶ ✶



Peridot — small or light-colored stones ✶ ✶



Pyrope — chrome type ✶ ✶



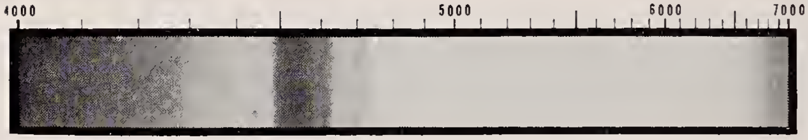
Quartz — green aventurine ✶ ✶

|—— VIOLET ——| VB |—— BLUE ——| BG |— GREEN —| YG | Y | O |— RED —|

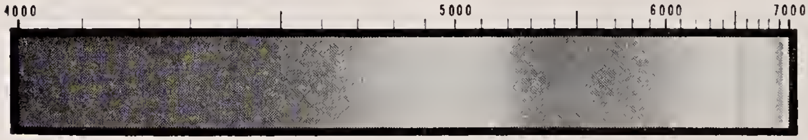
Absorption Spectra of Important Gemstones

Rutile – synthetic yellow and blue ✶ ✶

Sapphire – blue ✶ ✶



Sapphire – dark blue, green, Australian yellow ✶ ✶ ✶



Sapphire — natural and synthetic orange, purple, darkest tone of pink ✶ ✶

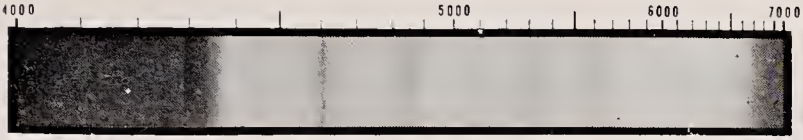
Sapphire — pale pink, orange, lavendar, violet-blue; and pale synthetic or natural chrome-bearing corundum ✶ ✶

Sapphire – synthetic green "imitation-emerald" color (5300 Å missing in same) ✶

|— VIOLET —| VB |— BLUE —| BG |— GREEN | YG | Y | O |— RED —|

Absorption Spectra of Important Gemstones

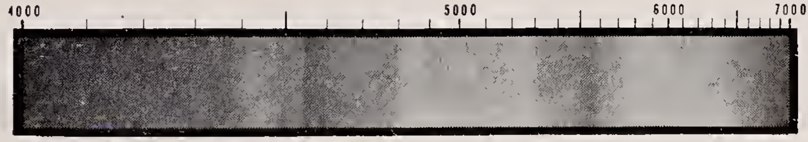
Sapphire – synthetic alexandrite-like type ✶



Spessartite – light orange, Amelia Court House type ✶ ✶ ✶

Spinel – dark blue stones, including gahnospinel ✶ ✶ ✶

Spinel – highly fluorescent red, pink and orange stones ✶ ✶



Spinel – light blue and violet ✶ ✶

Spinel – nonfluorescent garnet-red stones ✶ ✶

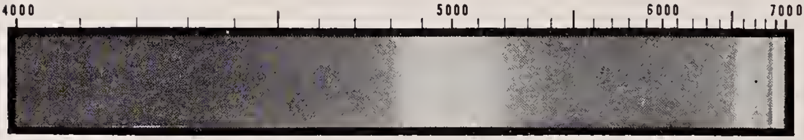
|—— VIOLET ——|— VB —|—— BLUE ——|— BG —|— GREEN —|— YG —|— Y —|— O —|— RED —|

Absorption Spectra of Important Gemstones

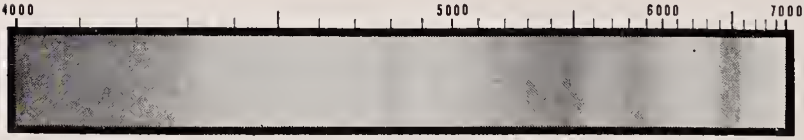
Spinel — synthetic red (.10-carat Verneuil stone) ✶ ✶

Spinel — synthetic red (.50-carat Verneuil stone) ✶ ✶

Spinel — synthetic red (hydrothermal)



Spinel — synthetic alexandrite-like



Spinel — synthetic lapis-lazuli imitation (reflected light) ✶ ✶

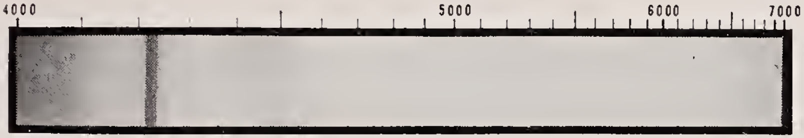
Spinel — synthetic pale blue (no manganese) ✶

VIOLET | VB | BLUE | BG | GREEN | YG | Y | O | RED

Absorption Spectra of Important Gemstones

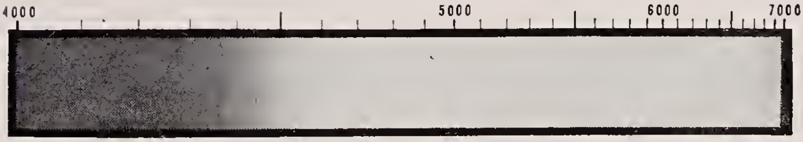
Spinel — synthetic pink ✶

Spinel — synthetic dark blue ✶ ✶ ✶

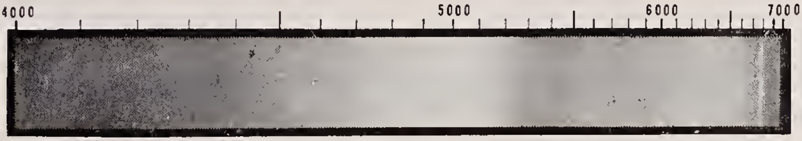


Spinel — synthetic green; yellow fluorescence ✶ ✶

Spinel — synthetic greenish blue (aquamarine color) ✶ ✶



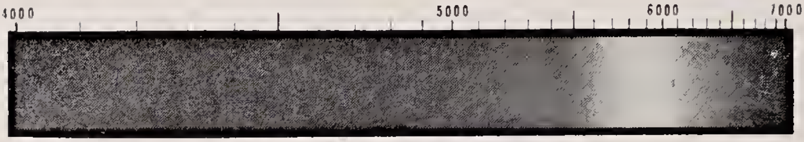
Spodumene — yellow-green ✶ ✶



Topaz — darkest tone of pink to light purplish red

|—— VIOLET ——| VB |—— BLUE ——| BG |— GREEN | YG | Y | O | RED —|

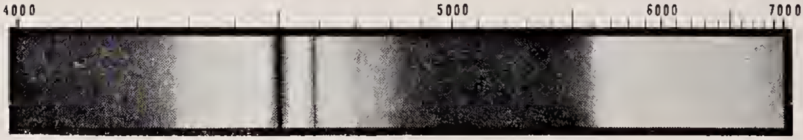
Absorption Spectra of Important Gemstones



Tourmaline – Ceylon brown and ordinary ray of dark green and dark blue ✶

Tourmaline – dark green and blue (extraordinary ray) ✶ ✶

Tourmaline — dark purple-red (orange ray) ✶ ✶



Tourmaline – dark purple-red (purple ray) ✶ ✶

Tourmaline red, brownish red, and darkest tone of pink ✶ ✶

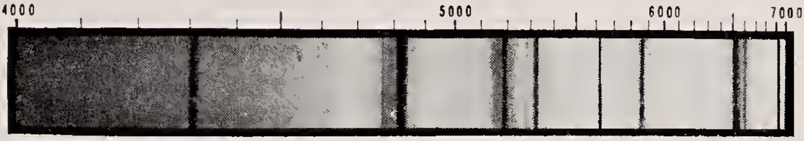
Tourmaline – lighter pink ✶

VIOLET | VB | BLUE | BG | GREEN | YG | Y | O | RED

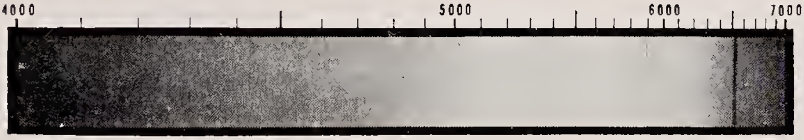
Absorption Spectra of Important Gemstones

Turquois – good color (reflected light) * *

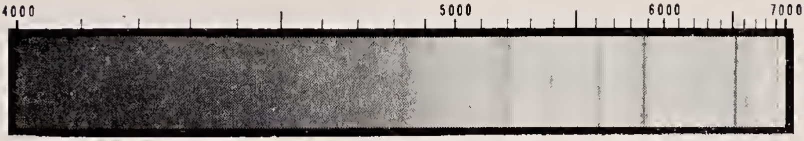
Zircon — Burma (extroardinary roy) * *



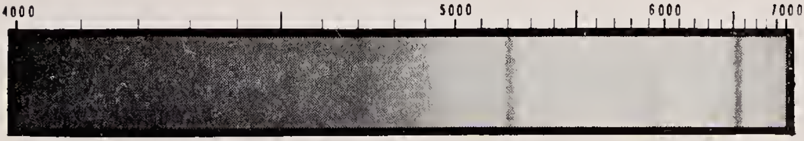
Zircon – Burmo (ordinary ray) * *



Zircon — heat-treoted blue and white (some have fewer, same mare of the typical bands seen in Ceylan stones) *



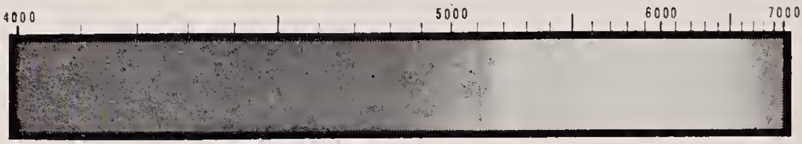
Zircon -- narmol Ceylon type (randam orientatian) * *



Zircon — normol gommo type * *

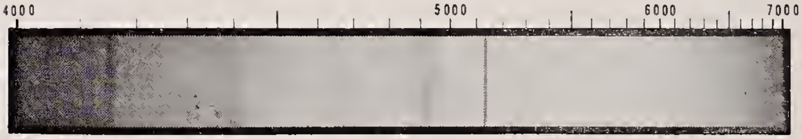
|—— VIOLET ——| VB |—— BLUE ——| BG |— GREEN |— YG | Y | O |— RED —|

Absorption Spectra of Less Important Gemstones

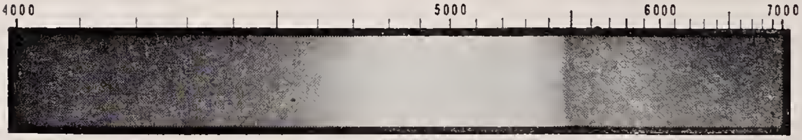


Actinolite — transparent crystal

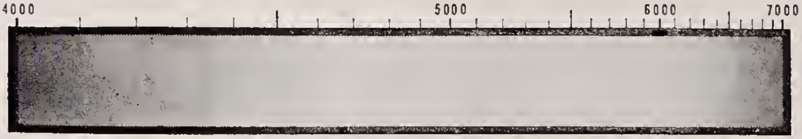
Apatite — yellow, green and colorless ✶ ✶ ✶
✶ ✶ ✶



Axinite — transparent ✶ ✶



Dioptase ✶

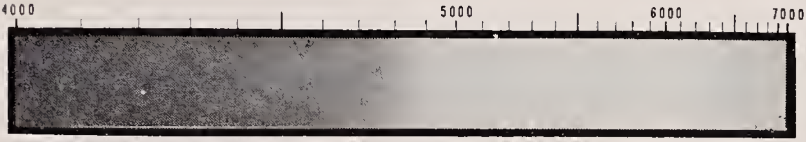


Diopside — ordinary green and brown ✶

Diopside — chrome type ✶ ✶

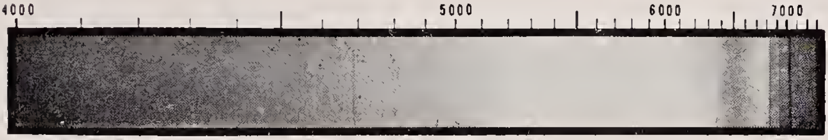
Absorption Spectra of Less Important Gemstones

Enstatite — brown ✶ ✶ ✶

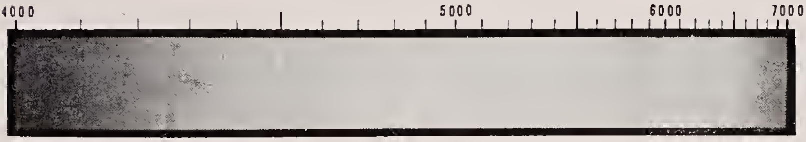


Enstatite — green ✶ ✶ ✶

Epidote ✶ ✶



Euclase — greenish blue ✶ ✶

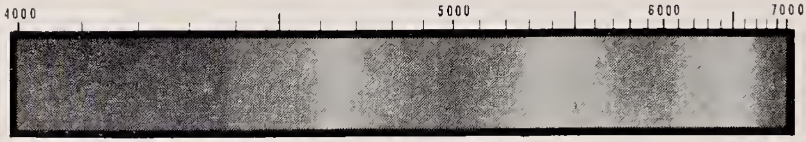


Fluorite — green (large or very dark pieces only) ✶

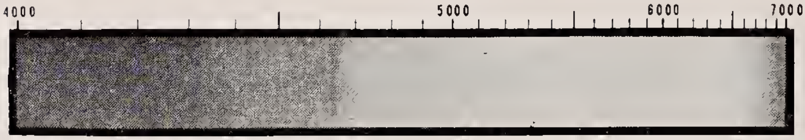
Gahnite ✶ ✶ ✶

VIOLET — VB — BLUE — BG — GREEN — YG — Y — O — RED

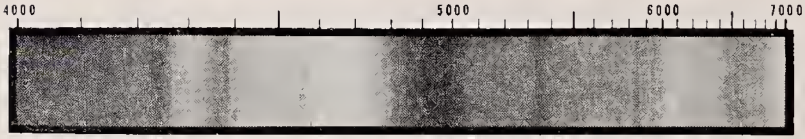
Absorption Spectra of Less Important Gemstones



Grossularite – pink (xaloxtacite) ✶



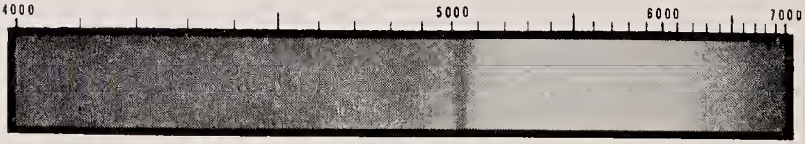
Idocrase – variety califarnite ✶ ✶ ✶



Iolite – large crystal (vialet ray) ✶

Iolite - large crystal (yellaw ray) ✶

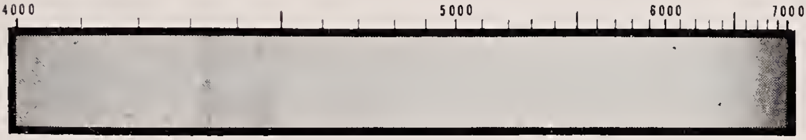
Iolite – small faceted stone ✶



Kornerupine - brown Burma stane (gamma ray) ✶ ✶

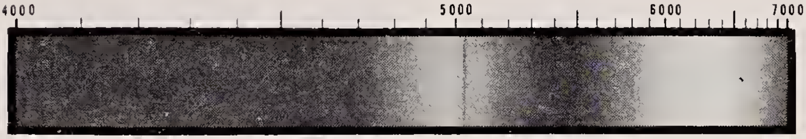
Absorption Spectra of Less Important Gemstones

Kornerupine — brown Burma stone (beta ray) ✶ ✶



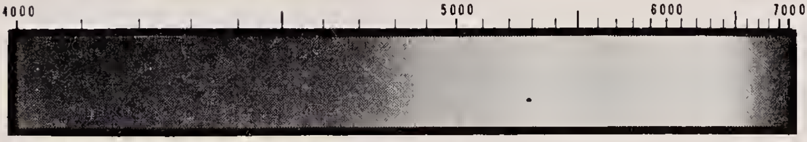
Kyanite green and some blue; others show nothing ✶ ✶

Rhodochrosite — translucent stone



Rhodonite — semitranslucent stone

Serpentine — (bowenite) chrome bearing, bright green ✶

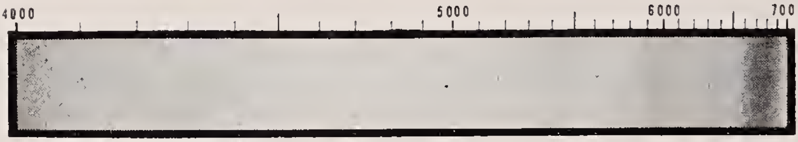


Serpentine — translucent dark green (contains black chromite octahedra) ✶

VIOLET — VB — BLUE — BG — GREEN — YG — Y — O — RED

Absorption Spectra of Less Important Gemstones

Sinhalite ✶ ★

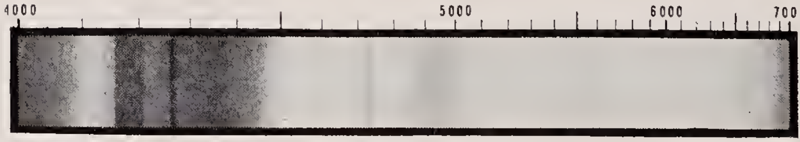


Sodalite – (strong transmitted light only) ✶

Sphalerite – (specimens with a greenish cast show this best) ✶ ✶

Thulite bright, light red (transmitted light) ✶

Variscite – translucent green (strong transmitted light)



Willemite ✶ ✶ ✶

|—— VIOLET ——| VB |— BLUE ——| BG |— GREEN | YG | Y | O | RED —|

Chapter XIV

Instruments Essential to Gem Testing

Success in gem testing is dependent on two factors: (1) experience and skill in instrument use, and (2) adequacy of equipment. It is possible to make an occasional identification by eye alone, but only in exceptional circumstances such as the detection of a garnet-and-glass doublet by the large difference in luster between its two portions. For the vast majority of gem identifications made by the jeweler, several gem testing instruments are essential. The ideal laboratory would contain every instrument that can aid in identification, no matter how seldom certain specialized equipment might be used. However, the expense of outfitting such a laboratory is prohibitive. In planning a gem testing laboratory, the average jeweler must weigh effectiveness against cost before deciding what instruments are essential for his purposes.

Three determinations are necessary in almost every identification: (1) refractive index, (2) single or double refraction, and (3) the shape of inclusions (to decide between synthetic and natural origin). The instruments discussed below are those which are most practical for use in making the three essential determinations. Since two other tests, specific gravity and an analysis of the absorption spectrum, are often necessary, the most practical instrumentation for these is also discussed.

The Refractometer. *Refractive index* is most easily determined by use of the gem refractometer. Refractometers range in price from $30 to 150[1]. The refractometer also may be used to determine

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[1] Gemological Institute of America, Los Angeles.

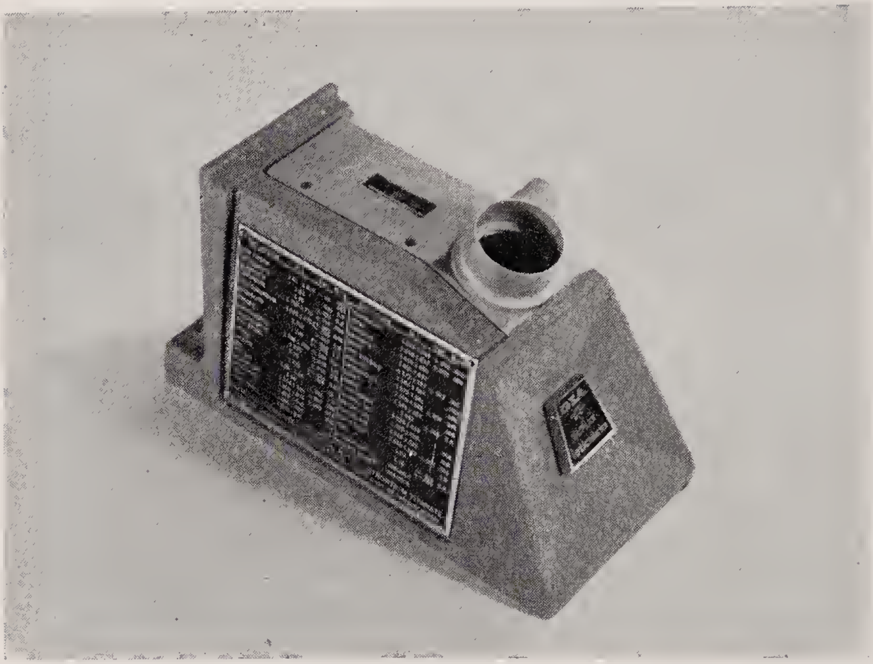

Figure 116
The GIA Duplex Refractometer.

birefringence and, occasionally, optic character. Although the refractometer is by far the most practical method of determining refractive index, others may be substituted if the necessary equipment is available. Other methods were discussed in Chapter V.

Since the determination of refractive index is required in the large majority of identifications, the practical and relatively inexpensive refractometer is essential to the gemologist.

The Polariscope. The most practical instrument available for use in distinguishing between single and double refraction is the polariscope.[2] The polariscope is also used to detect pleochroism and optic character.

Although its accuracy is questionable, the reflection test (Chapter VI) is often used in distinguishing between single and double refraction.

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[2] Gemological Institute of America, Los Angeles

Magnifiers. Probably the most important instrument in gem identification is a good magnifier, combined with a light source designed for effective illumination of the interior of transparent gemstones. There are three such instruments currently available. The first of its type in this field, the Diamondscope, is an American Gem Society product. The Gemolite and Gem Detector are binocular microscopes with built-in illuminators available from the Gemological Institute of America. The price range for these instruments is from well under two hundred to slightly over five hundred dollars. Monocular microscopes without illuminator bases are available from about thirty to several hundred dollars, depending on the number of different magnifications, plus the quality of the optics and mechanical parts.

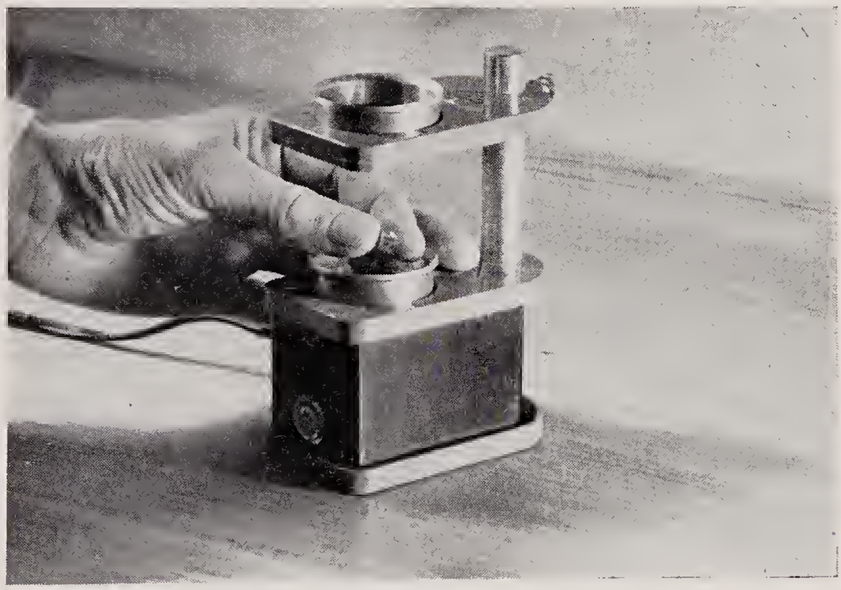

Figure 117

The Gem polariscope in use.

The Spectroscope. Prism spectroscopes are available from small hand units up to large table models. Hand models without scales may be obtained for less than one hundred dollars, and table spectrometers for five to fifteen hundred dollars or more. A complete unit employing a high-intensity lamp on a flexible arm that permits either transmission or reflection, a prism to reduce the heat on the specimen, an iris diaphragm to act as a light shield of variable size, and a Beck wave-length model hand spectroscope mounted on a movable arm, is available for less than $400.

Specific Gravity Determination. A fourth test upon which the gemologist must often depend is the determination of specific gravity. The most practical of the many means of specific gravity determination is the use of the diamond balance with attachments that permit the weighing of the gem in a liquid. Since the diamond balance is standard equipment in the average jewelry store, and the attachments necessary for specific gravity determination are inexpensive or easily constructed, this method is the most practical for the jeweler. Liquids of high density are excellent for rapid determination. Their value is not limited by the fact that few satisfactory liquids are readily available, since it is possible to prepare liquids of intermediate value by mixing two such liquids, providing the two are miscible in all proportions. Heavy liquids permit determinations on tiny stones on which reliable results are not possible on the standard diamond balance.

LESS FREQUENTLY USED GEM TESTING INSTRUMENTS.

The *dichroscope* is a small instrument used for the determination of pleochroism. The value of the dichroscope is limited since its use is confined to the determination of pheochroism. The presence of pleochroism is proof of double refraction, but its absence is NOT proof of single refraction—especially in the light colored stones.

The Gemological Microscope. The polarizing microscope with the changes necessary for the examination of gemstones is an instrument that may be used for a number of tests, but it is cumbersome and not as well adapted to the testing of gemstones as are the Binocular Gemolite, polariscope, and refractometer, the indi-

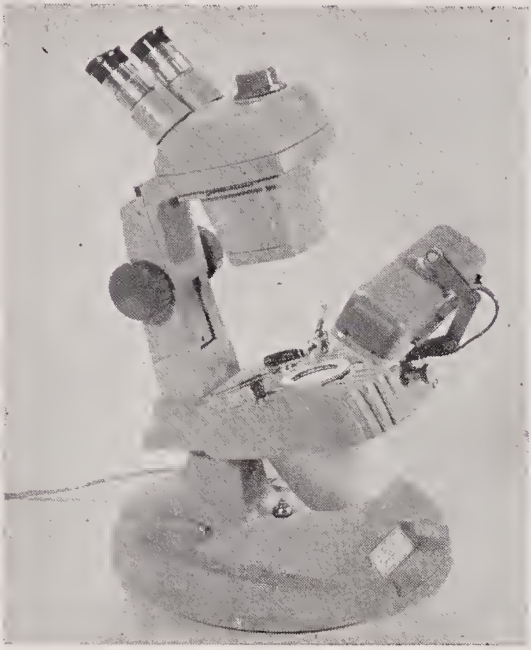

Figure 118
The Gemolite.

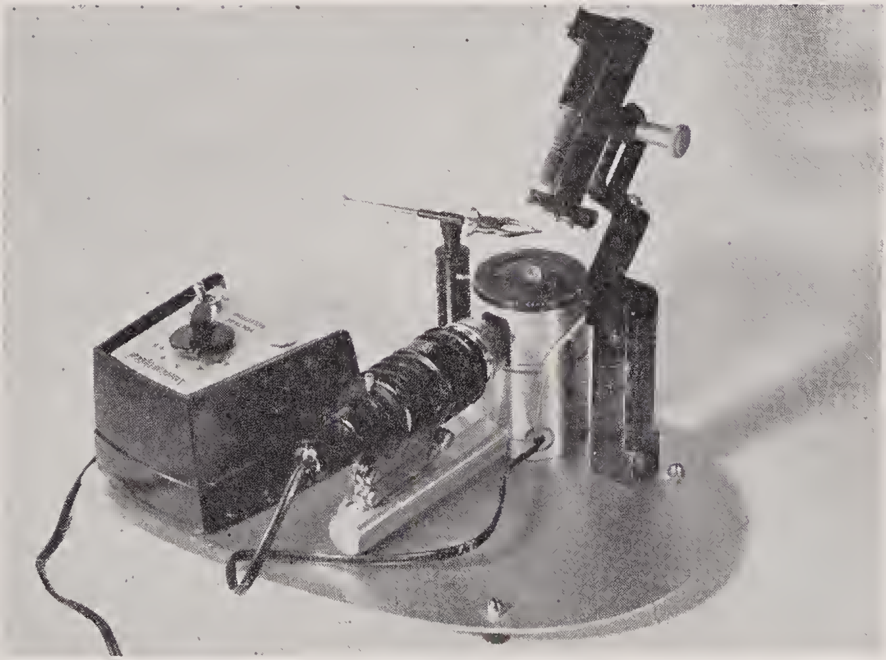

Figure 119
The GIA Spectroscope Unit.

vidual instruments which perform tests it may be used to duplicate. The gemological microscope, an expensive instrument. requires training and practice to be used effectively and its use for most tests is more time-consuming than that of the instruments designed especially for gem identification. It may be used for the determination of refractive index, optic character, and pleochroism, as well as for magnification.

Ultra-violet lamps. Ultra-violet radiation of certain wave lengths excites fluorescence in many materials. The nature of the fluorescence may be of value in identifying the gem which exhibits the property. The most effective wave lengths are 2500Å. and 3660Å. Different models of the Mineralight provide 2537Å and 3660Å wave lengths, and the GIA Hand Fluorescent Unit is a long-wave source. The short-wave lamp is about forty and the long-wave lamps under thirty dollars.

Hardness Points and Plates. Hardness points and plates, the traditional means of gem testing, are used by the present-day gemologist only as a last resort when all other tests fail to produce a positive identification. They are almost never needed in the testing of transparent gemstones, but become important to the gemologist in the identification of opaque gems. They are inexpensive and easily used, but careless handling may easily result in irreparable damage to a fragile gem. While scratches on the back of an opaque gem do not detract from its beauty, similar marks on the pavilion facets of a transparent gem may be visible from the crown. Since they are often necessary to the correct classification of opaque gemstones, hardness points or plates are essential to the gemological laboratory.

A Monochromatic Light Source. The increased clarity and sharpness of refractive index readings in sodium light makes the monochromatic sodium lamp an important instrument in the complete laboratory. The use of a monochromatic light source in conjunction with the refractometer enables the gemologist to determine birefringence and, occasionally, optic character, in addition to obtaining accurate index readings.

Chapter XV

Descriptions and Property Variations of Gemstones

Amber varies in diaphaneity from transparent to semitranslucent and from light yellow to dark brown in color, although reddish and greenish-browns are not unknown. In addition, amber is dyed all colors. It is characterized by its very low specific gravity—near 1.08. Baltic amber is usually lighter in color than Sicilian, Rumanian, or that from Burma. Amber, an amorphous gem material, has a refractive index near 1.54. It is easily distinguished from plastic imitations by the fact that it floats in a saturated salt solution, while plastics sink. Amber may contain spherical bubbles, as well as irregular foreign fragments and insects.

Reconstructed or pressed amber, made by application of heat and pressure to fragments of amber is best distinguished by magnification, which discloses elongated gas bubbles in contrast to spherical bubbles in amber. Glass-like flow lines also may be apparent. Copal, a natural resin of more recent age which, like amber and pressed amber, floats in saturated salt solution, softens under a drop of ether. Amber is not affected. The hardness of amber is 2 to 2.5. It is sectile.

Amblygonite, a triclinic lithium-aluminum fluophosphate, has been found in a colorless, yellow, or light-brown transparent form. Indices for gem quality crystals are usually near 1.612 and 1.636 and the optic sign is positive. The hardness is 6, the specific gravity is near 3.02, and it has perfect cleavage in a basal plane. Repeated twinning is common in two directions at 90°.

Anatase, rutile and brookite are all different crystalline forms of titania. Rutile and anatase both occur in the tetragonal system and brookite is orthorhombic. Anatase occurs in a brown color when in transparent, gem quality. It is characterized by indices of 2.493 and 2.554, a specific gravity of 3.9, and a hardness of 5.5 to 6.

Andalusite occurs in yellow-green to brownish-green colors, with an overtone of a brownish-red color caused by pleochroism often evident in one direction. It is also found in a yellow-brown and a green color. The strong pleochroism may lend andalusite a bicolored effect similar to that associated with alexandrite, but without the strong changes under different lights. The refractive indices are near 1.634 (±.006) to 1.643 (±.004) and the specific gravity 3.17 (±.04). The birefringence varies from .008 to .013, with the highest birefringence when indices are lowest. It is distinguished from tourmaline by its lower birefringence and biaxial optic character. Andalusite crystallizes in the orthorhombic system and is optically negative in sign. The pleochroism of the green variety is brownish-red and brownish-green. Andalusite has a hardness of 7 to 7.5, and has distinct to perfect cleavage with an angle between the two directions of nearly 90°.

Apatite is very rarely encountered as a gem material, but occurs in transparent form in blue, violet, purple, yellowish-green to bluish-green, colorless, and yellow colors. Only in the blue apatite is the dichroism strong, blue and yellow being the typical dichroic colors of blue apatite from Burma. Apatite is characterized by very low birefringence .002 to .006. The indices are 1.642 (—.012, +.003) to 1.646 (—.014, +.005). The specific gravity is 3.18 (±.02). Apatite has a hardness of 5, no cleavage, weak dispersion, and is uniaxial negative. See Chapter XIII for typical absorption spectra.

Apophyllite is a mineral in the zeolite family, which is very rarely cut and then only for collectors. It is only 4.5 to 5 in hardness, has a specific gravity of 2.3 to 2.5, and indices of 1.535 and 1.537. In its gem quality, it is usually pink in color and semitransparent. A hydrated potassium-calcium fluosilicate, apophyllite crystallizes in the tetragonal system.

Augelite is an aluminum phosphate that sometimes occurs in colorless, or nearly colorless, and slightly brownish crystals. Properties: hardness, 4; specific gravity, 2.70; monoclinic; indices, 1.574 and 1.588; sign, positive.

Axinite, a complex silicate sometimes fashioned for collectors, occurs in purplish-brown, brownish-yellow, and violetish-blue colors. It may be confused with chrysoberyl, hessonite garnet, topaz, or tourmaline in the yellow variety, but the other colors are distinctive. Axinite occurs in the triclinic system (thus is biaxial) and has a negative optical sign. Although it has only distinct, not easy cleavage, it fractures easily. It is 6.5 to 7 in hardness. The refractive indices are 1.678 (±.005) and 1.688 (±.005), the birefringence near .010, and the specific gravity 3.29 (±.02). See Chapter XIII for typical absorption spectra.

Azurite is employed more for ornamental objects than as a gemstone, but is used especially in American Indian jewelry. It is a semitranslucent to opaque, dark violetish-blue mineral frequently found and cut with lighter green malachite, thus appearing as a mottled green and blue stone. Azurite has a large birefringence sometimes apparent by the "spot method" of index determination. Indices are 1.73 to 1.84. The specific gravity is about 3.80 if compact, but occasionally porous azurite floats in methylene iodide (3.32). Azurite has a hardness of 3.5 to 4, and a pale blue streak. It effervesces under a drop of hydrochloric acid.

Benitoite is a rarely encountered gemstone resembling blue sapphire. It occurs in colorless and light to dark blue transparent stones, with violetish tints caused by strong dispersion often apparent as the stone is turned. It is easily identified by its high birefringence (.047), indices 1.757 to 1.804, and specific gravity 3.64 (±.03). High birefringence distinguishes benitoite from sapphire. The dichroic colors of blue benitoite are deep blue and nearly colorless and of violet benitoite, reddish-gray and purple-violet. The dispersion of benitoite is about equal to that of diamond but it is seldom cut to display it. It is uniaxial, with a positive sign and its hardness is 6 to 6.5. It does not possess easy cleavage. The largest fine stone known is of seven carats. Today a good stone of two carats or above is a rarity. It fluoresces light-blue under short-wave ultra-violet light.

Beryl. The color range of beryl is among the widest of the important gemstones, although most varieties occur in light tones. In addition to the familiar emerald and aquamarine colors, beryl produces lovely light purplish-red to light red-violet, yellow, greenish-yellow, brownish-yellow, and colorless stones. Rarely, aquamarines from Madagascar and some violetish-red stones are fairly deep in color. Attractive orange beryl is found in Brazil. Dark-brown material may show asterism, and chatoyancy is possible in most colors.

The properties of the varieties of beryl vary somewhat, so they will be listed individually. (See Chapter XIX.)

	Refractive Indices	S.G.
Aquamarine	1.575 (±.005) and 1.580 (±.005)	2.71 (±.03)
Emerald	1.577 (±.008) and 1.583 (±.009)	2.72 (±.02)
Yellow	1.570 (±.003) and 1.575 (±.004)	2.70 (±.02)
Red to violet	1.585 (±.006) and 1.594 (±.006)	2.82 (±.05)

The birefringence of beryl increases with increasing refractive index from .005 for yellow beryl and most emerald to .007 for African emerald and .009 for the red to violet variety. Beryl crystallizes in the hexagonal system, has no perceptible cleavage, and is uniaxial negative. Dispersion is very low. See Chapter XIII for typical absorption spectra.

Since beryl occurs in such a wide color range, it may be confused in one or more of its varieties with one or more varieties of many other gemstones. Aquamarine may be confused with topaz, synthetic spinel, tourmaline, zircon, apatite, fluorite, sapphire, synthetic sapphire, doublets, triplets, and glass. The standard tests permit easy separation.

Emerald in one or more qualities may resemble the following: synthetic emerald, tourmaline, peridot, demantoid garnet, sphene, dioptase, fluorite, apatite, chrysoberyl, zircon, semitransparent jadeite, doublets, triplets, and glass. With the exception of synthetic emerald (described in Chapter X), separation is simple by the standard procedure. Morganite may be confused in appearance with spodumene (kunzite), tourmaline, topaz, corundum, synthetic corundum, synthetic spinel, rhodolite garnet, phenakite, scapolite, doublets, and glass. The only natural gemstone with similar property values, scapolite, is easily identified by its greater birefringence. Other varieties of beryl, such as colorless, yellow, and brown may resemble topaz, hessonite garnet, quartz, tourmaline, chrysoberyl, sapphire, scapolite, synthetics, doublets, and glass. Easy separation is accomplished by standard tests, except for scapolite described above.

Most beryl varieties of deeper colors exhibit fairly distinct dichroism. Emerald—green and blue-green. Aquamarine—colorless to light blue and darker blue (very weak if heat-treated). Morganite—light red and violetish-red (weak). Other varieties are very weakly dichroic.

Beryllonite is a very rare mineral sometimes fashioned as a gemstone. It is transparent colorless to light yellow. The refractive indices of 1.552 to 1.562 are between those of beryl and quartz which it resembles, but its biaxial optic character and specific gravity 2.85 (±.02) separates beryllonite. Beryllonite has a perfect cleavage plus a direction of good cleavage at right angles to this. Its hardness is 5.5 to 6.

Brazilianite is a transparent yellowish-green mineral discovered in a Brazilian pegmatite dike during World War II and later described by F. H. Pough, Ph.D. It is more a collector's piece than a true gemstone. Brazilianite has an easy two-directional cleavage and may be sufficiently shattered to appear translucent. The refractive indices are near 1.602 and 1.621, birefringence .019, with a specific gravity near 2.94. It is biaxial, with a positive optic sign; has a hardness of 5.5; and weak pleochroism. It is also bleached to colorless form.

Brazilianite may be confused with topaz, tourmaline, chrysoberyl, and especially apatite. The refractive index test separates it from chrysoberyl and birefringence from topaz or apatite.

Calcite is a very common mineral (calcium carbonate) which occurs in transparent to semitranslucent forms in a wide variety of colors. The only extensive jewelry use it finds is in the onyx marble variety which is used for lamp bases and other ornamental objects and in carved onyx- or agate-like forms dyed green and other jade colors. The latter form is sold incorrectly as "Mexican Jade." It is distinguished from jade by its strong banding.

Massive calcite in the form of either limestone or marble is used for carvings in a white color or dyed to imitate coral and other ornamental materials.

Calcite has refractive indices of 1.486 and 1.658, and is uniaxial negative. The indices and birefringence of .172 are nearly constant. The specific gravity is near 2.71.

Single crystal calcite possesses very easy three-directional cleavage, not apparent in the crystalline aggregate forms used for ornamental purposes. Calcite has a hardness of 3 and effervesces strongly to hydrochloric (muriatic) acid. The excessive birefringence is apparent on crystalline aggregates of calcite if the "spot method" of refractive index determination is employed. It may be necessary to try different orientations of the stone and to rotate a Polaroid plate before the refractometer eyepiece to obtain results.

Cassiterite is well known as a mineral but very rarely fashioned as a gemstone. In a transparent form, pale yellow to dark red-brown stones are sometimes faceted. Translucent to opaque dark brown cassiterite is seen in cabochon form. The refractive indices are near 1.996 to 2.09, so the birefringence is great. The high (6.95) specific gravity serves to identify cassiterite. Its hardness is 6 to 7.

Chlorastrolite is a dark green semitranslucent material characterized by a radial fibrous structure. It is employed infrequently in cabochon form for jewelry. Each cabochon contains a number of roughly spherical areas of tiny radial groups. Chlorastrolite often has patches or veins of white to pink thomsonite. The structure is such that chlorastrolite cabochons sometimes exhibit a chatoyant effect in each of the small areas, or a broad sheen. It is a darker, less intense green than malachite. The usual refractive index is near 1.66, specific gravity about 3.2, and hardness 5 to 6.

Chrysoberyl. Although chrysoberyl is best known for the finest cat's-eye, transparent faceted chrysoberyl is a fairly common gemstone. As in the cat's-eye variety, light to medium tones of greenish to brownish-yellow are most common, but yellow-green and greenish-brown to almost red stones are known. When a chrysoberyl shows a pronounced color change from purplish-red under incandescent artificial light to green in daylight it is called alexandrite.

The gemstones with which chrysoberyl are most often confused include sapphire, zircon, peridot, synthetic corundum and spinel, beryl, tourmaline, yellow diamond, quartz, doublets, and glass.

Chrysoberyl crystallizes in the orthorhombic system and is optically positive. The refractive indices are near 1.746 (±.004) and 1.755 (±.005). The specific gravity is very near 3.73 (±.02). On the refractometer, chrysoberyl behaves much as if it were uniaxial, for the intermediate index is seldom more than .001 higher than the lowest index numerically. The two directions of distinct cleavage are 60° apart, but rarely in evidence. Chrysoberyl has weak dispersion. It is fairly tough and has a hardness of 8.5. See Chapter XIII for typical absorption spectra.

The alexandrite variety exhibits strong trichroism with slight color differences between artificial and daylight. The colors are green, orange, and red, with the latter tending toward violetish-red in daylight. Yellow, yellow-brown, and yellow-green chrysoberyls exhibit from weak to distinct dichroism corresponding to lighter and darker tones of the stone's color. Synthetic corundum and synthetic spinel which display a pronounced color change from incandescent artificial light to daylight are called incorrectly "synthetic alexandrite" in the trade. The synthetic corundum changes from a purple resembling amethyst under artificial light to a grayish-blue in daylight, bearing little resemblance to alexandrite. Synthetic spinel changes from red to green in colors similar to the genuine, but, of course, it is not pleochroic. Its refractive index of over 1.73 may be confused with that of chrysoberyl on hasty determination.

Copal, Kauri Gum, and Dammer Resin are natural resins of recent age. While resembling amber in appearance and properties, they become sticky rather quickly under a drop of ether. The refractive index is near 1.54, and specific gravity near 1.06. See Chapter XX for separation from amber.

Coral is a semitranslucent to opaque material occurring as their branchlike framework of a colony of marine invertebrates. Gem coral occurs in white, pink, orange, red, and black colors. The black type differs from the white to red in that it is not largely calcium carbonate, but a horny substance. Calcareous coral has properties near those of calcite. Calcite fibers radiate from the center of each branch in the plane normal to the length. Each branch shows a striped appearance under magnification parallel to the length of the branch. The luster on fractures is dull.

Refractometer readings are usually vague, but if a spot reading is used, the huge birefringence of calcite (refractive indices 1.486 and 1.658) is usually evident with a Polaroid plate. The high index is constant. Specific gravity is usually within .05 of 2.65. Hardness is 3.5 to 4. Black coral has indices of about 1.56 and 1.57, birefringence near .01, specific gravity about 1.37, and a hardness under 3. Unlike coral, the black horny type fails to effervesce under hydrochloric acid. It shows a coarse interrupted tree-ring structure in cross section of the branches. This is emphasized by small crescent-shaped sections of white color.

Coral is easily distinguished from conch pearl by the latter's odd mosaic pattern, produced by shiny reflections seen in certain directions. The 2.85 specific gravity of conch pearl also distinguishes it. White coral is often imitated by conch shell worked into various shapes. The curved layered structure of the shell identifies it.

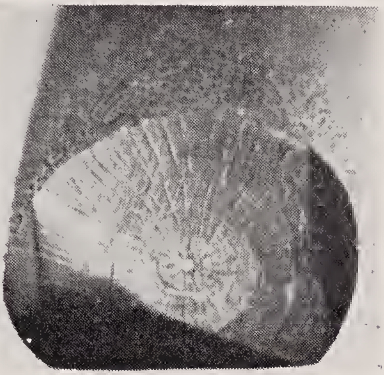

Figure 120

Corundum is, in many respects, the most important of the colored stones. Ruby and sapphire are more familiar to and cherished by the layman than any other gem varieties with the possible exception of emerald. Ruby includes only the medium to dark tones of red to violetish-red. All other colors including purple, violet, and light red are properly called sapphire. Slightly reddish-orange natural sapphires are called padparadsha properly, but the term is not used frequently today. Other colors include very light to very dark blue to violetish-blue, bluish-green, yellowish-green, yellow, brown, nearly opaque black, and colorless. One variety shows a color change of the type familiar in alexandrite, but the change is weaker and the daylight color is basically blue and the artificial light color is violetish-red to purple. Semitransparent to semitranslucent stones of almost all colors found in the transparent varieties have been fashioned to display asterism when the essential silk-like inclusions are present. Both 6 and 12 rayed stars have been found. In addition to the colors mentioned above, many asteriated stones are light gray to white. Yellow and green star sapphires are very rare as is chatoyant corundum.

There are many gemstones which may resemble one or more varieties of corundum. These include spinel (blue, red, violet), zircon (colorless, yellow, blue, green), chrysoberyl (yellow, brown, and vaguely, alexandrite), pyrope, almandite, and rhodolite garnet (red, purple, and violet), topaz (colorless, yellow and brown, light blue), tourmaline (light to dark red, blue, green), benitoite (blue), spodumene (light red to violet), beryl (light blue, yellow, light red to red-violet), hessonite garnet (yellow to brown), quartz (pale stars, colorless, yellow), synthetic corundum (stars, all colors of transparent), synthetic spinel (blue, and light colors), glass (all colors), doublets (most colors).

Of the gemstones and substitutes named, only synthetic corundum, rhodolite and almandite garnet, benitoite, and chrysoberyl have similar property values. The identification of synthetics is discussed in Chapter X. Rhodolite and almandite are singly refractive, so they are not dichroic and exhibit no doubling of facet edges. Great care in the use of the polariscope is necessary to distinguish the anomalous double refraction of some garnet from true double refraction. Benitoite has a birefringence over five times as great as sapphire plus a lower specific gravity, and a positive optic sign. Chrysoberyl has perceptibly lower refractive indices and specific gravity.

Ruby, plus green, yellow, and blue sapphire show distinctive absorption spectra, permitting easy separation of ruby from garnet and these colors of sapphire from synthetic counterparts. Ruby and synthetic ruby show no appreciable difference in spectra.

Corundum crystallizes in the hexagonal system and possesses four directions of parting or false cleavage which may be well developed. The repeated twinning which causes parting may cause a gemstone to remain light in all positions in the polariscope as well as imparting a broad-banded appearance under magnification. The refractive indices of corundum are usually near 1.762 and 1.770, but rare stones (especially dark red and green) may give readings as high as 1.778 without significant change in the normal birefringence of .008. Corundum is uniaxial and negative in optic sign, so the numerically higher reading is the constant one. The specific gravity of gem materials is 4.00 (±.03), and the hardness 9. The dispersion of corundum is very low. Many of the corundum varieties are strongly dichroic. Ruby generally exhibits light orangy-red and dark violetish-red as dichroic colors, but in dark stones and those tending toward violet, orange and violet is a more accurate description. Blue sapphire—light greenish-blue and dark violetish-blue dichroic colors, with very dark stones showing green and dark violet. Orange to yellow-brown corundum exhibits orange to yellow-brown with the depth depending on the color of the stone, and the other color nearly colorless. As in the yellow variety, dichroism is weak. Green sapphire—green to blue-green and yellow-green.

Danburite is a rare mineral most often found in transparent colorless to yellow crystals which may be faceted for collectors. It may be confused with any of the colorless or yellow gemstones of the medium index range. The refractive indices are close to those of topaz 1.630 (±.003) and 1.636 (±.003) but the specific gravity is much lower 3.00 (±.01). The birefringence remains constant at .006. Danburite is biaxial, with the intermediate index just halfway between the extremes. It has no distinct cleavage, and its hardness is 7. Most danburite fluoresces in a light blue color under ultra-violet radiation.

Datolite is a hydrated calcium borosilicate that occurs both in transparent greenish crystals and in semitranslucent white, red, yellow or amethystine form resembling porcelain. It is a secondary mineral usually found in veins and cavities in basic igneous rocks. It occurs in the monoclinic system; shows no cleavage; has a hardness of 5 to 5.5; specific gravity, 2.9 to 3.0; and refractive indices of 1.626 and 1.670. It is optically negative.

Diamond, the most important gemstone, is usually transparent and nearly colorless, but yellow to brown stones are not rare and light tones of violet, green, blue, and red are known. Non-transparent black diamonds are sometimes faceted. Gemstones which approach diamond in refractive index, unlike diamond, are doubly refractive, usually with strong birefringence. The high luster, single refraction, 3.52 specific gravity, and extreme hardness all distinguish diamond.

Although brilliant-cut nearly colorless diamonds are usually recognized by jewelers at a glance, the usual colors in other cuts, and deep colors in any cut sometimes are not so readily recognized. Colorless zircon, synthetic spinel, synthetic sapphire, and recently, synthetic rutile are mounted to pass off as diamonds. Careful examination of these under magnification will reveal doubling except in synthetic spinel, in which bubbles are usually evident and which has a refractive index near 1.73. Calibre diamonds in mountings stand out in relief when immersed in bromoform, or methylene iodide, in contrast to stones of lower refraction which are sometimes substituted for some of the diamonds. Under magnification, characteristics are also likely to be revealed that are unique in diamond among colorless, transparent stones of high luster. Cleavage, "naturals," the unusual appearance of the lathe-turned girdle surface on a brilliant, and the sharpness of facet edges all suggest diamond. See section devoted to diamonds in Chapter VIII.

TREATED DIAMONDS. For many years diamonds occasionally were subjected to the radiation of radium salts for thc purpose of imparting a green color. Stones so tested retained a dangerously high degree of radioactivity. Radium treatment is easily detected by the residual radioactivity by Geiger counter or by placing the stone in contact with unexposed film (or film in a light-tight paper holder) for twenty-four hours. Radioactivity causes exposure, leaving a photographic impression of the area of the diamond in contact with, or adjacent to, the film. Another characteristic of radium-treated green diamonds may be detected under magnification: flat, disclike brown spots slightly beneath the surface. The advent of the methods that produce stones safe to wear, using the cyclotron and the nuclear reactor, made the radium method obsolete.

If a diamond is placed in the path of highly accelerated subatomic particles in the beam of a cyclotron or exposed to bombardment by neutrons in a nuclear reactor, short exposure causes a change to a green color, which deepens to black as exposure continues. Apparently, the color is caused by electrons knocked from their regular positions in the structure and which then occupy vacant spaces between their normal positions, forming so-called color centers. These may cause color by scattering or partial absorption of transmitted light or by absorption and re-emission of light in a new wave length. Heat treatment causes partial healing of the lattice damage, but not all. The result of heat treatment is a change from green to a yellow or brown color.

Stones colored by certain types of particles in the cyclotron are characterized by a shallow penetration and a strongly zonal color distribution. This is evident under magnification in the form of a pattern around the culet that has been likened to either a "cloverleaf" or an "umbrella." Zones of color, giving a pattern similar to the facets, may also be seen.

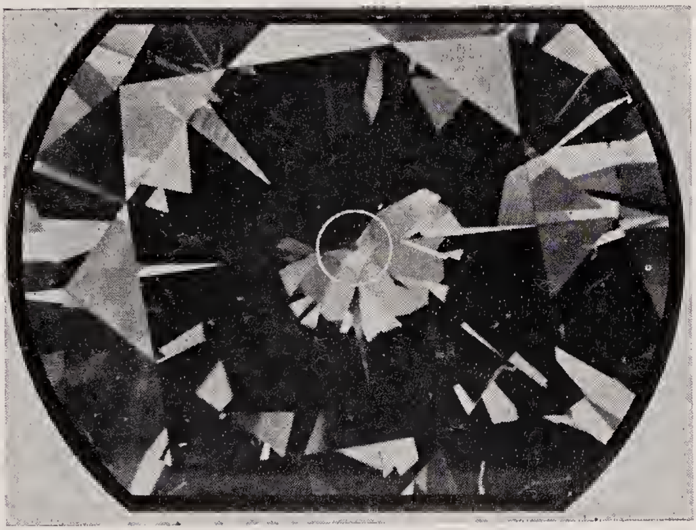

Figure 121
Cloverleaf, or umbrella, effect.

Green stones subjected to neutron bombardment in the cyclotron or a radioactive pile have color throughout and are not detectable by color zoning. However, either radioactive pile- or cyclotron-irradiated diamonds colored yellow or brown by subsequent heat treatment are distinguishable by the presence of a narrow absorption band, at 5920Å. Robert Crowningshield, GIA's Gem Trade Laboratory Director in New York City, who developed this test, has been able to detect the line in all but less than ten of over 10,000 stones examined that were known to have been treated. Narrow absorption lines are also to be seen at 4980 and 5040Å. These may be present in both natural and treated yellow diamonds, but in treated stones the 4980Å line is usually the stronger of the two, in contrast to natural yellow and brown stones.

The 5920Å line, the key to detection of this type of treatment, is often elusive. If the stone is heated too much by the powerful light source, the line is temporarily lost. Often, it is to be seen only in one position in one direction. Presence of the line is proof of treatment, but its absence should be given weight only when the spectroscopist is experienced in this test, has efficient equipment, and has given the stone an exhaustive examination without permitting its temperature to rise more than a few degrees above room temperature.

Diamonds are often coated to improve their color. A fluoride coating of the type applied to lenses (or other chemicals resistant to most of the ordinary solvents) which masks the diamond's yellow body color, is used. It may be removed by boiling the diamonds in concentrated sulphuric acid. Usually, it is applied to the pavilion in sufficient depth to impart an irridescent sheen when light is reflected from the pavilion facets. Occasionally, it is applied thinly only at or near the girdle. This type is apparent only when the gemologist is attempting to compare the color with that of uncoated diamonds. A dark grayish cast is cause for suspicion. Unless the coating can be seen under magnification, removing it by boiling out is the only way to prove its presence.

Diopside is a common mineral, rare in gem quality, that is fashioned occasionally for collectors. It is usually yellow to green in a transparent to translucent form, but may be colorless or blue. In appearance, diopside may be confused with peridot, demantoid garnet, zircon, enstatite, tourmaline, chrysoberyl, emerald, and epidote. The refractive indices are 1.675 (—.010, +.027) to 1.701 (—.007, +.029). In the usual hue of green, the darker the color, the higher the indices and gravity. The specific gravity is 3.29 (±.03). The birefringence of diopside (.024 to .028) is much less than that of peridot and the reaction which may be obtained on a refractometer using monochromatic light is biaxial positive. The pleochroism is weak. Diopside has perfect cleavage, characteristic of the pyroxene group of minerals and also parting. Diopside may be chatoyant. The violetish-blue variety is called violane.

Dioptase is a rarely encountered intense green transparent mineral which, in its best quality, resembles fine emerald in appearance. It is easily identified by its high birefringence (.053). Refractive indices are 1.655 (±.011) to 1.708 (±.012) and specific gravity (3.30, ±.05). It is uniaxial with a positive sign. Dioptase when faceted is usually in very small stones. It has perfect cleavage in three directions and its hardness is 5. Its pleochroism is weak.

Dumortierite when used for gem purposes is a compact, massive, semitranslucent dark-blue basic aluminum borosilicate mineral that resembles sodalite more closely than lapis-lazuli. It has refractive indices of 1.678 and 1.689; specific gravity, 3.30; and a hardness of 7. It is optically negative (beta, 1.686). It is easily distinguished from lapis-lazuli and other nontransparent blue minerals by its high refractive index and specific gravity.

Ekanite. F. L. D. Ekanayaki, Ceylonese gem dealer and gemologist, bought two dark-green faceted stones on the market in Colombo, because they looked unlike any gem that he knew. Tests he performed indicated glass, but inclusions belied that identification. One specimen examined by British scientists proved to contain calcium, lead, thorium and silicon. The samples tested are all highly radioactive. It is apparent that this is a metamict mineral similar to green, low-property zircon, but one in which structural breakdown has been more complete; it is now amorphous but inclusions show that it was once tetragonal. The refractive index is 1.597 and the specific gravity is 3.28.

Enstatite is a transparent to translucent yellowish-green to brownish-green mineral rarely fashioned as a gemstone. It may be confused with chrysoberyl, tourmaline, peridot, zircon, and diopside. It has refractive indices of 1.658 (±.005) to 1.668 (±.005) and a specific gravity of 3.25 (±.02). The low birefringence

(.010) distinguishes enstatite from peridot and diopside. Enstatite which may be chatoyant, is biaxial positive. It has easy cleavage, with about 88° between the two directions; hardness of 5.5; and weak pleochroism. It may be recognized immediately by a very strong, sharp absorption line at 5060Å.

Epidote is a common mineral infrequently fashioned as a gemstone. While usually yellowish to brownish-green, it is known in reddish, yellow, and gray colors—from transparent to semi-translucent in diaphaneity. The refractive indices are 1.729 (—.015,+.006) to 1.768 (—.035,+.012), specific gravity 3.25 to 3.50. Most epidote is green with strong pleochroism (green, dark brown, and yellow). The birefringence (.019 to .045, usually .030 to .040) at this point on the refractive index scale identifies epidote. Epidote has excellent cleavage. Although epidote of gem quality is usually biaxial negative, material with higher indices may be positive.

Euclase is a mineral which, but for its extreme rarity, probably would be an important gem mineral. It has the requisite beauty and hardness (7.5). Euclase occurs in transparent colorless, light blue, or light green colors. It may be confused with beryl, topaz, and the many colorless gemstones in the middle refractive index range. The refractive indices are 1.654 (±.004) to 1.673 (±.004) with a birefringence nearly constant at .019, and specific gravity very near 3.10. It is biaxial positive, with the optic sign easily determined in most cases with monochromatic light on a refractometer. Euclase has one very easy direction of cleavage.

Feldspar Group. The important rock-forming feldspar minerals furnish a number of gem materials of which the most frequently encountered are moonstone, amazonite, and labradorite. The feldspars all cleave very easily in one direction, and nearly as easily in another at or near 90° to the first. If any tiny breaks are present, the cleavage will be apparent.

Albite-Oligoclase. For convenience albite and oligoclase of the plagioclase series of feldspars are grouped as one gem specie. Although most fine moonstone is a variety of orthoclase (adularia), some moonstone has higher properties corresponding to those of albite and oligoclase. Since both types of moonstone are feldspar, no differentiation is made between them, but the gemologist must be prepared to find a moonstone occasionally which has property values higher than those of orthoclase. Moonstone is the name applied to a semitransparent colorless stone with a white to pale blue floating light. The variety sunstone is a translucent to semitranslucent white, light gray, or yellowish, with red-brown to orange spangles of hematite. If green spangles are present it is called aventurine. Refractive indices of albite-oligoclase are 1.532 (±.007) to 1.542 (±.006), and specific gravity 2.62 (±.02). The cleavage is easy, and a second direction at about 85° to the first is slightly less easy.

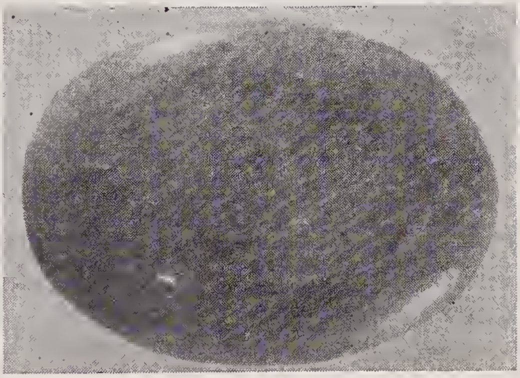

Figure 122

A microcline cabochon illuminated from the side.

Labradorite is found usually as a semitranslucent gray material exhibiting broad iridescent color effects. It has been cut in a transparent yellow form, without the familiar color effect. The gray material is usually seen in cabochon or scarab form. The refractive indices are 1.559 (±.005) to 1.568 (±.005), and the specific gravity 2.70 (±.05). The angle between the two cleavages is about 86°.

Microcline, although known in a variety of colors, is used as a gem material almost only in the light blue-green amazonite variety. It is semitranslucent in gem quality and is characterized by a grid-like surface appearance. Microcline has refractive indices of 1.522 (±.002) to 1.530 (±.002). The specific gravity is 2.56 (±.01). The angle between the two cleavage directions is just less than 90°.

Orthoclase feldspar is best known for the moonstone variety, which is semitransparent and colorless with a floating blue light. It also occurs in a light yellow transparent form without the floating light. Moonstone is not closely imitated by any other natural gemstone, although milky chalcedony is sometimes confused with it. Glass, synthetic spinel and plastic imitations may bear a closer resemblance. The transparent orthoclase may be confused with citrine, yellow beryl, pale yellow topaz, or glass.

Refractive indices are close to 1.518 and 1.526. Specific gravity is 2.56 (±.01). Bear in mind that moonstone varieties of the plagioclase feldspars (especially albite and oligoclase) will exhibit higher property values. Orthoclase has perfect and near perfect cleavage in two directions at 90°. This cleavage can be detected if even tiny breaks are present. This provides one of the methods of distinguishing between any of the feldspars and chalcedony, with which they are often confused.

Fluorite or fluorspar is a soft mineral occurring in a number of lovely colors. Ornaments such as vases, snuff bottles, and statuettes are carved from fluorite. Although used extensively for this purpose, it is faceted as a gemstone but rarely. While commonly green, blue, or violet, it is known in other colors. Fluorite occurs in the cubic system and has easy, perfect cleavage. The refractive index is very close to 1.434 and the specific gravity is 3.18 (±.01). It has a hardness of 4. It rarely keeps a good polish and, as the low index indicates, it has rather poor luster.

Garnet Group. The gem species of the garnet group all occur in the cubic crystal system, have no apparent cleavage, and tend to fracture fairly easily. Many garnets, although singly refractive, exhibit a strain or anomalous double refraction in the polariscope. All garnets have a high luster.

Almandite occurs in colors from medium red-violet to dark brownish-red. Contrary to popular use, the dark brownish-red color is as common in almandite as in pyrope or Bohemian garnet. Some almandite when cut *en cabochon* exhibits asterism either by reflected or transmitted light. Usually the star has four rays.

Almandite is most often confused with ruby, especially the dark Siam grade, but it may also be confused with glass, doublets, synthetic corundum, and spinel. Almandite frequently exhibits very strong anomalous double refraction. However, this will not produce the doubling of facet edges and strong dichroism always found in ruby. In addition, "silk" in almandite will be in only two directions in any one plane, while it is in three directions in the same plane in ruby. Their absorption spectra differ markedly.

Almandite has a refractive index of 1.80 (±.03) and specific gravity of 4.05 (±.12).

Andradite garnet occurs in green, black, and yellow varieties, of which the green demantoid variety is used most frequently as a gemstone. The color of demantoid varies from light yellowish-green to medium to dark green. It is characterized by its brilliancy and high dispersion (.057, which is greater than diamond). Demantoid is one of the few gemstones containing inclusions so characteristic as to permit positive identification—the so-called horse-tail inclusions described earlier. Demantoid is still incorrectly called "olivine" by many dealers. Demantoids are usually of small size, stones over four carats are extremely rare. Demantoid may be confused with emerald, peridot, tourmaline, sapphire, spinel, sphene, glass, and doublets. The refractive index is 1.875 (±.020). The specific gravity 3.84 (±.03). See Chapter XIII for typical absorption spectra.

Grossularite garnet is known in nature in a variety of colors including yellow, brown, white, colorless, green, and orangy-red, but for gemstones only two varieties are encountered frequently. Transparent orangy-yellow to orangy-brown grossularite, known as hessonite or essonite among stone dealers, is an attractive richly colored gemstone. An excellent jade-like form often misnamed "South African Jade" or "Transvaal Jade" occurs in a translucent to semitranslucent slightly yellowish-green color and is characterized by the presence of small black inclusions visible to the naked eye. Hessonite may be confused with topaz, spessartite, doublets, beryl, citrine quartz, sapphire, and chrysoberyl. The translucent green grossularite may be confused with jadeite, nephrite, idocrase, or serpentine. The refractive index of grossularite is 1.735 (±.015), with hessonite usually near 1.745 and green grossularite 1.725. The specific gravity is 3.61 (—.04,+.12).

Pyrope garnet occurs in transparent to semitransparent dark brownish-red to red colors. Since the property values of pyrope are rarely close to the gemstones which resemble it in appearance, it usually offers less difficulty in identification than almandite. The gemstones with which it is confused on sight alone are ruby, synthetic ruby, glass, doublets, tourmaline, and spinel. Although the refractive index of pure pyrope is 1.705, such material is rarely if ever encountered in nature. Pyrope below 1.735 is very rare, although 1.72 to 1.73 has been reported. Readings between 1.74 and 1.75 are most common. The specific gravity is 3.78 (—.16,+.09). When pyrope has a low index, it could be confused with spinel. Separation is best effected by a study of inclusions or by spectroscopy. Pyrope contains stubby rounded prisms of very low relief, and often needle-like crystals in two directions in the same plane. Spinel is characterized by the presence of octahedra either individual or in planes.

Rhodolite garnet is the name applied to a mixture of pyrope and almandite. Rhodolite tends to be lighter in color than either pyrope or almandite and it is usually violetish-red or a slightly brownish-red-violet. Rhodolite may be confused with ruby, "plum" sapphire, spinel, tourmaline, synthetic corundum, doublets, beryl, and glass. The properties of rhodolite are intermediate between those of pyrope and almandite. The refractive index is usually 1.76 (±.01) and the specific gravity 3.84 (±.10). Rhodolites of over five carats are rare.

Spessartite garnet is but rarely used as a gemstone. As a gemstone it is usually transparent yellow to yellow-brown, but dark orangy-brown stones have been reported. It resembles closely the hessonite variety of grossularite, and may be confused with brown zircon, sphene, topaz, tourmaline, citrine, glass, doublets, and beryl. The refractive index is 1.80 (±.01) and the specific gravity 4.15 (±.03). The hardness is 7 to 7.5.

Figure 123
Botryoidal hematite. Note splintery fracture (left).

Hambergite is a rare beryllium borate that is occasionally cut as a gemstone when it is encountered in transparent crystals. Its principal recommendation is its hardness of 7.5. In a gem form, it is a colorless, transparent material marked by a high birefringence: indices are near 1.555 and 1.626. It is positive in sign, with the beta index at 1.586. It crystallizes in the orthorhombic system and has perfect prismatic cleavage; it also has good pinacoidal cleavage, so it is quite fragile. The specific gravity is 2.35.

Hematite is an opaque dark gray to black mineral with a metallic luster. It is carved for cameos and intaglios. It is characterized by a red-brown streak and a splintery fracture. Only the substitute first marketed as "hemetine" resembles hematite. It is distinguished from hematite by its rough to nearly waxy fracture. Much of the early material also had a black streak and a high specific gravity (up to 7.0). The best of these hematite substitutes has the same gravity and streak, requiring either examination of a fracture surface or X-ray diffraction for detection. A stamped impression of a carving would of course eliminate hematite. Stamped impressions are found in steel which is also used as a hematite imitation. Steel has a metallic streak and a specific gravity of 7.7 or more. Spherical beads of hematite have been offered as "black pearls" while faceted hematite has been called "black diamond." Hematite has a specific gravity of 5.20 (±.08), and a hardness of 5.5 to 6.5. See Chapter XXVII for identification details.

Idocrase or vesuvianite is best known as a gem material in its translucent californite variety, an aggregate which resembles jade. Rarely, transparent greenish-brown to green single crystal material is faceted for collectors. The californite variety occurs in a translucent somewhat mottled yellowish-green with white to light gray. It resembles poor quality jade and substitutes.

Idocrase is doubly refractive, crystallizing in the tetragonal system. No cleavage direction is easy or perfect in the material. The refractive indices 1.713 (±.012) to 1.718 (±.014), the birefringence near .005 and it is uniaxial negative. The specific gravity of idocrase is about 3.30 to near 3.5, but the jade-like material is nearer the lower figure (it just floats in pure methylene iodide, or sinks slowly). The hardness is 6.5. See Chapter XIII for typical absorption spectra.

Iolite, also known as cordierite and dichroite, is considered a gem material when transparent. It occurs in blue to purple colors of low intensity and is characterized by very strong trichroism. The trichroic colors are usually colorless to light yellow, blue, and dark blue-violet to violet. Distinct cleavage in one direction is sometimes noted. Iolite crystallizes in the orthorhombic system, and is biaxial negative. The gemstones that may be confused with iolite include sapphire, spinel, quartz, and tourmaline. The close property value approximation of quartz causes no difficulty in identification because of iolite's strong pleochroism. The refractive indices are 1.542 (—.010,+.002) to 1.551 (—.011,+.045) and the specific gravity 2.63 (±.05). The hardness is 7 to 7.5.

Jade includes both jadeite and nephrite. The former is known also as "Chinese or Burmese Jade" and the latter as "Siberian, New Zealand, or Spinach Jade."

Jadeite is a semitransparent to nearly opaque mineral which furnishes the finest jade. It occurs in green of high intensity, mottled green and white, white, violet, brown, orangy-red, and yellow colors. In its finest green color nothing but emerald and glass bear a close resemblance in appearance. In poorer qualities and other colors jadeite may be confused with nephrite, idocrase, grossularite, soapstone (talc), glass, serpentine, sillimanite, prehnite, and chalcedonic quartz. Jadeite, a mineral of the pyroxene group, crystallizes in the monoclinic system, and is optically biaxial positive. Although jadeite has two directions of easy, perfect cleavage (at angles of 93° and 87° as in spodumene), the aggregate structure conceals it except in the rare case that the grain size is large, when it imparts a bladed appearance. The refractive indices are 1.66 (±.007) to 1.68 (±.009) but a single hazy reading near 1.66 is most common. The specific gravity 3.34 (±.04) and the hardness is 6.5 to 7.

There are several other materials bearing a superficial resemblance to jade that are sometimes carved as inexpensive substitutes for it. Pseudophite (better known by the misnomer, "Styrian jade," from its source, Styria, Austria), resembles serpentine but is a variety of a chlorite-group mineral; refractive index near 1.57, specific gravity 2.7, hardness 2.5. Agalmatolite, or pagoda stone, a compact, massive alteration product related to muscovite mica and pyrophyllite, is also frequently carved by the Chinese; refractive index between 1.55 and 1.60, specific gravity 2.75-2.80, hardness 2.5 to 3.5. Saussurite, another alteration product, is largely zoisite;

refractive index 1.70 to 1.71, specific gravity usually slightly under 3.3, hardness 6.5. Verdite is a combination of the green chrome-mica. fuchsite, in a clay; refractive index near 1.58, specific gravity about 2.9, hardness 3.

Translucent, light-colored jadeite may be identified conclusively by a strong sharp line at the edge of the violet at 4370Å in the spectroscope. This line is often concealed by general absorption in that region in deep-green stones or in dyed stones. It is difficult to see in opaque or nearly opaque stones. Distinguishing between dyed and natural green jadeite may be accomplished by the spectroscope. The distinct differences between dyed and undyed material are shown in the table of spectra in Chapter XIII. In dyed jadeite that has faded somewhat, the dye band is often visible only when light is passed through a long section of the piece.

Nephrite, a tough, compact variety of actinolite or tremolite, minerals in the amphibole group, is an important jade mineral. It is translucent to opaque and is found in dark green, gray, white, blue-green, yellow, black, and red colors. The most important type is that known as "Spinach or Chinese Jade" which is a fairly dark green of lower intensity than the green of jadeite. Gem materials confused with nephrite include amazonite, serpentine, jadeite, soapstone (talc or steatite), sillimanite, idocrase, prehnite, grossularite, chalcedonic quartz, and glass.

Like jadeite, nephrite would exhibit perfect cleavage (two directions at 56° and 124°) except for its finely crystalline aggregate structure. A splintery fracture is ascribed to nephrite, but it is seldom evident. More common is a rough fracture with a dull luster. The refractive indices are 1.61 (±.005) to 1.63 (±.008), with the usual appearance on the refractometer, a broad reading near 1.61. The specific gravity is 2.95 (±.05) and hardness 6 to 6.5.

Jet is a fine-grained compact opaque black variety of coal which has long been used as a gem material because it takes an excellent polish and is easily carved. It is imitated by glass, plastics, and a vulcanized rubber product.

Jet is amorphous, has a hardness of 2.5 to 4, a specific gravity of 1.32 (±.02), and a refractive index of 1.66 (±.02). The fracture is rough and has a dull luster.

Kornerupine is a rare mineral occasionally used as a gemstone. It appears most frequently in parcels of gemstones from Ceylon, usually labeled tourmaline. As a gemstone it is transparent in colorless, yellow, brown, and green. It may be confused with tourmaline of the dark greenish-brown type common in Ceylon, peridot, beryl, topaz, and quartz. Kornerupine crystallizes in the orthorhombic crystal system, and is biaxial negative with the high and intermediate indices close together. The refractive indices are close to 1.657 (±.002) and 1.680 (±.003): the birefringence near .013; the specific gravity, 3.30 (±.05); and the hardness 6.5. Easy, perfect (two-directional) cleavage often is evident. The pleochroism is strong, especially in the Ceylon material, with very dark reddish-brown and yellow-green as the predominant colors. In light green kornerupine, green and yellow to red-brown are observed.

Kyanite is a mineral infrequently cut as a gemstone. It occurs in light to dark blue, green, colorless, and brown colors in a transparent form with the blue color most used in gemstones. The blue color usually exhibits fairly strong zoning. Kyanite is of interest because of the extreme variability of hardness with direction, with a 4 to 5 hardness encountered in one and 7 in another. Very easy cleavage is encountered in one direction and a less perfect cleavage at 74° to the first. Kyanite crystallizes in the triclinic system and is biaxial negative. The refractive indices are near 1.716 and 1.731 and the specific gravity 3.62 (±.06). In dark blue kyanite, the pleochroism is nearly colorless, dark blue-violet, and blue. Finest gem quality kyanite is most likely to be confused with sapphire and spinel, and lighter material with aquamarine, topaz, synthetic spinel, and light sapphire.

Lazulite is a blue mineral usually encountered as a gem material when in a translucent to semitranslucent form with a blue color resembling lapis lazuli in appearance. It has been faceted on rare occasions when found in small intense blue transparent crystals. In most cases the lapis-like material is mottled with white.

Lazulite may be confused with lapis lazuli (it is often called "False Lapis"), sodalite, azurite, dyed chalcedonic quartz, and, perhaps, fluorite. Lazulite crystallizes in the monoclinic system and is biaxial negative. The refractive indices are near 1.61 and 1.64. The specific gravity is 3.09 (±.05) and the hardness 5 to 6. Cleavage is indistinct. The transparent material shows dark violetish-blue and colorless to light blue as dichroic colors.

Lazurite or hauynite (lapis lazuli) is an intense blue to violetish-blue semitranslucent to opaque material long used as a gemstone because of its beauty of color. Lapis lazuli is characterized by the presence of small metallic yellow inclusions of pyrite.

The gem materials substituted for lapis lazuli and which may be confused with it include lazulite, sodalite, azurite, dyed chalcedonic quartz, glass, sintered synthetic spinel and plastics. A drop of hydrochloric acid on lapis reacts to the extent that a distinct hydrogen sulphide (rotten eggs) odor is detectable, in contrast to substitutes.

The mineral of which lapis lazuli is a variety crystallizes in the cubic system. No cleavage is evident. The refractive index is near 1.50 and the hardness is 5 to 6. Although the specific gravity is usually near 2.75, it varies considerably, depending on the amount of pyrite and other impurities. Material with 2.60 readings are uncommon, but it is not rare for material rich in pyrite to reach 3.00.

Leucite is a colorless potassium-aluminum silicate, with a hardness of 6, and a specific gravity of 2.5. Some of the rare transparent colorless crystals have been cut for collectors. It is a pseudocubic material that shows approximately a .001 birefringence. Its refractive indices may be as low as 1.504-1.505 to 1.508-1.509. It appears to have a high degree of dispersion, but the color is caused by interference in thin repeated twinning lamellae.

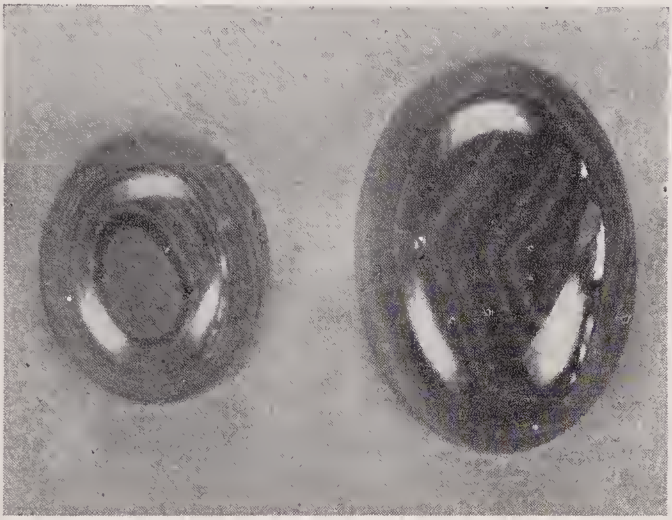

Figure 124
Typical agatelike banding in malachite.

Malachite is a semitranslucent to opaque light to dark yellowish-green mineral used principally for ornamental purposes but it is also cut *en cabochon*. Malachite frequently is banded with light and dark green colors alternating in a pattern similar to agate. In addition, a radial fibrous structure with a high luster on the individual needles lends some malachite an attractive sheen. Since malachite occurs with azurite, a deep violetish-blue mineral, cut malachite may exhibit blue patches of azurite. The only gem materials which conceivably could be confused with malachite are very poor quality green turquoise, variscite, dyed calcite, glass, and plastics.

Malachite crystallizes in the monoclinic system and has a hardness of 3.5 to 4 if compact. Porous material may be softer. The refractive indices are near 1.66 and 1.91. The high birefringence may be evident upon rotation of a Polaroid plate before a "spot" reading on the refractometer. The specific gravity for compact material is near 3.95, but some malachite is so porous that it floats in methylene iodide (3.32).

Marcasite is described not because it is used in jewelry, but because the name marcasite is applied to pyrite which is employed extensively in "marcasite" jewelry. Hematite is used less often for the same purpose. Marcasite is an opaque pale metallic yellow, lighter and more gray than pyrite. Upon exposure, the color deepens markedly on the surface of this unstable material.

Marcasite is orthorhombic; has a hardness of 6 to 6.5; a grayish to brownish-black streak; and breaks down rapidly, turning an unattractive brown. Marcasite has a specific gravity of 4.85 (±.05).

Moldavite, probably a natural glass, was discovered over 150 years ago in Bohemia and Moravia. Other glasses of the same apparently meteoric origin have been discovered, but only the transparent yellowish-green material from that area has been used to any extent as a gemstone.

Moldavite may be confused with beryl, peridot, artificial glass, doublets, triplets, tourmaline, topaz, and chrysoberyl. The refractive index of moldavite is usually near 1.48, but may be as high as 1.52. The specific gravity is 2.40 (±.04), and the hardness about 5.5. The internal appearance is similar to that of artificial glass in that flow lines and bubbles are encountered.

Obsidian is a volcanic glass sometimes fashioned as a gemstone. Although most obsidian is black and nearly opaque, rather transparent green, brown, and yellow material is known. Semi-transparent dark brown to black obsidian is seen most frequently in cut stones and a black material with attractive white patches is known as flowered obsidian. It is rarely confused except with varieties of quartz, from which it is easily separated by its single refraction and low property values. Obsidian has a refractive index of 1.50 (±.02), specific gravity of 2.40 (±.06), and a hardness of 5 to 5.5. Flawed obsidian may give a polariscope reaction similar to that of chalcedony, but the vitreous luster on fracture surfaces of obsidian distinguishes it from chalcedony. Tiny black inclusions are distributed generally, but may be concentrated in rough layers. Some of the inclusions may be elongated prisms of the dark minerals which crystallize early in the cooling of a granite magma.

Odontolite, otherwise known as "bone turquoise" or "fossile turquoise," is composed of fossilized bones and teeth of extinct vertebrates colored blue by the iron phosphate mineral vivianite. It was mined for a number of years from deposits in southern France. In color and general appearance, it provided an effective turquoise substitute. Compact material has a hardness of about 5; specific gravity, 3.1; and a refractive index that varies somewhat with phosphate-carbonate compositional variation. Usually a vague reading near 1.60 is obtained. The birefringence becomes obvious (if the calcite content is large) when a Polaroid plate is used in front of the spot. Since there is always some calcite present, hydrochloric acid causes effervescence. A structure characteristic of an organic material is visible under magnification. The acid test provides the fastest means of separation from turquoise.

Opal is an amorphous hydrous silica in some varieties of which vivid colors are produced by light interference. The varieties which display this color effect include white opal (colorless to white body colors), black opal (gray to nearly black body colors), and some opal with an orange body color also exhibits the play of color. Other varieties without the play of color include orange to orangy-red transparent material called fire opal, and nontransparent opal in a number of colors, resembling chrysoprase, jasper, and other chalcedonic quartz.

Glass imitations of fine black and white opal bear little resemblance to the natural material, nor do other gemstones. Opal doublets, employing a thin natural opal top are common. Fire opal may be confused with glass and the nontransparent varieties, with chalcedonic quartz.

Opal has a hardness of 5 to 6.5 and a specific gravity of 2.15 ($-.17, +.07$). The refractive index is very low. Most white and black opal is near 1.45, but a range of 1.40 to 1.50 has been noted. Fire opal may give readings as low as 1.37. In general, fire opal has a refractive index below that of glass employed as gem imitations. In contrast to chalcedony which may resemble some varieties of opal, the luster on opal fracture surfaces is vitreous.

Painite, a dark-red gem mineral, was discovered in the gem gravels in Mogok, Burma, by the well-known gemologist and gem collector, A. C. D. Pain. Only two or three stones have been found in the period since it was first reported in 1957. It is uniaxial with a negative sign, has refractive indices of 1.787 and 1.816, the pleochroism is pale brownish-orange to ruby red, the specific gravity is 4.01, and the hardness is 8.

Peridot is the name applied by jewelers to the mineral known to mineralogists as olivine. The term chrysolite has also been applied to the material, especially to that which is pale in color. Gem quality peridot is transparent and occurs in yellowish-green, green, greenish-yellow, brownish-green, and brown colors. It may be confused with demantoid garnet (often called "olivine" by jewelers), emerald, tourmaline, chrysoberyl, zircon, sapphire, synthetic sapphire, synthetic spinel, doublets, natural and artificial glass.

Peridot is a magnesium-iron silicate, which in fine quality contains much more magnesium than iron. Since the proportions vary in different deposits, some property variation is to be expected. However, gem peridot in the usual green color or the rare brown color is usually near 1.654 and 1.690 in refractive indices, with a birefringence near .036. The specific gravity is usually near 3.32 to 3.35, but slightly higher readings are encountered occasionally. Peridot is lower in index than sinhalite and may be distinguished by both lower indices and by the fact that the beta index is always near the midpoint between alpha and gamma. Sinhalite has a beta index only about .010 below the high gamma index. The absorption spectra differ materially. (See Chapter XIII.)

Petalite is a lithium-aluminum silicate that sometimes occurs in transparent colorless crystals. It crystallizes in the monoclinic system and has perfect basal cleavage and good prismatic cleavage as well; therefore, it is rather fragile. The hardness is 6; the refractive indices about 1.502 and 1.518, with a positive sign; and the specific gravity is near 2.40. It is nonfluorescent under long- and short-wave ultra-violet, but fluoresces yellowish-orange under X-rays, phosphorescing for several seconds.

Pollucite is a mineral occurring in colorless cubic crystals. It is sometimes cut for collectors, because of its hardness of approximately 6.5. It is a caesium-aluminum silicate with a refractive index within .005 of 1.52. Its specific gravity is within .02 of 2.92. The only gem quality material is found in Maine.

Phenakite is a rare mineral which is cut almost entirely for collectors. It occurs in transparent crystals usually colorless, but sometimes is light yellow or light red. It may be confused in appearance with any of the colorless or pale gemstones in the medium refractive index range, such as topaz, quartz, beryllonite, tourmaline, spodumene, and others.

Phenakite crystallizes in the hexagonal system. It is uniaxial positive. The refractive indices are 1.654 (—.003, +.017) to 1.670 (—.004, +.026), the specific gravity 2.95 (±.01), and the dispersion .015. Phenakite has a hardness of 7.5 to 8, and no distinct cleavage. Specific gravity and optic character permit effective separation from spodumene which has nearly the same indices.

Prehnite is a fairly common mineral but seldom used as a gemstone. It is usually a light yellowish-green in color and semitransparent to translucent. The lighter color and greater transparency distinguish it in appearance in most cases from nephrite which it approximates in properties. Other light-colored jade substitutes such as chrysoprase, serpentine, and idocrase may be confused with prehnite.

Prehnite is usually found in crystalline aggregates of tiny orthorhombic crystals. The refractive indices are near 1.616 and 1.649. In contrast to nephrite, which seems to give a fairly strong reading only near 1.61, prehnite usually gives an indistinct reading nearer the middle of its range at 1.625 to 1.635. The specific gravity is 2.88 (±.06), either barely floating or sinking very slowly in pure bromoform (2.89). Distinct cleavage may be evident. Prehnite has a hardness of 6 to 6.5, and is biaxial positive.

Pyrite is included as a gem material because of its wide use under the name marcasite. It is an opaque, pale metallic yellow mineral, which has no important imitations in the jewelry field because of its low price. However, to avoid the yellow color, hematite is used in place of pyrite in some "marcasite" jewelry. The hardness of pyrite is 6 to 6.5; its specific gravity near 5.0; its streak black; and it crystallizes in the cubic system. No cleavage is apparent.

Quartz, the most common single mineral, includes so many varieties and sub-varieties that have been fashioned as gemstones that a number of books have been written on this species alone.

There are two prominent subspecies of quartz, crystalline and cryptocrystalline. Gemstones from transparent crystalline quartz are cut usually from single crystals, while other stones cut from crystalline quartz may include in the fashioned stone a number of crystal grains. The grain size is large compared to that in cryptocrystalline material. Mineral collectors and amateur lapidaries have applied variety names to thousands of types of chalcedonic quartz. In this descriptive section, only the most important gem categories will be mentioned.

CRYSTALLINE VARIETIES. Colorless, transparent quartz is called rock crystal. In appearance it may be confused with any of the colorless gemstones and substitutes in the medium and low refractive index ranges. Transparent light to dark purple to violet quartz is called amethyst. There are many gemstones which exhibit colors somewhat similar to those of various grades of amethyst. These include among others tourmaline, kunzite, synthetic and natural sapphire and spinel, some garnet, zircon, apatite, and fluorite. The dichroism of amethyst is weak, with purple and reddish-purple the dichroic colors in fairly dark material.

Semitransparent to translucent light red to violetish-red quartz is called rose quartz. Not infrequently rose quartz is asteriated, in which case it is frequently improved by backing the cabochon with a colored mirror. In appearance only tourmaline and fluorite are likely to resemble rose quartz.

SMOKY QUARTZ and cairngorm are names applied to dark brown grayish-yellow to almost black, transparent to semitransparent quartz. Obsidian, tourmaline, and glass are most likely to produce gemstones similar in appearance.

Transparent light to dark yellow, yellow-brown, orange-brown, reddish-orange, and brown quartz is called citrine by mineralogists and topaz quartz by jewelers. Some colored stone dealers incorrectly call finer qualities topaz alone, while others misrepresent all citrine as topaz. Citrine or topaz quartz may be confused in appearance with topaz, hessonite, beryl, sphene, tourmaline, zircon, synthetic or natural sapphire, doublets, glass, chrysoberyl, and transparent orthoclase.

Transparent to semitransparent, single crystal quartz also occurs in a light to dark yellowish-green color produced by heat-treatment of certain amethyst. This material, to which no variety name has been applied, is somewhat similar in appearance to some colors of chrysoberyl, zircon, demantoid, peridot, tourmaline, and glass.

AVENTURINE QUARTZ is the name applied to translucent quartz which contains many tiny highly reflective or intensively colored inclusions. The inclusions are hematite, mica, or one of a number of colored minerals. Depending on the nature of the inclusions, aventurine may resemble aventurine feldspar, glass ("goldstone"), jade, or jade substitutes.

TIGER-EYE is the name applied to a pseudomorph of quartz after crocidolite asbestos which retains the fibrous structural appearance of the asbestos. Tiger-eye is usually yellowish-brown in color and translucent, but it is dyed or bleached to a number of other colors. Its appearance is fibrous with the fibers somewhat wavy. The result is similar to a wavy chatoyancy. Tiger-eye has a fracture that is splintery.

CAT'S-EYE quartz has a straight fibrous appearance in contrast to the wavy fibrous structure of tiger-eye. It occurs in gray-brown, green, and greenish-yellow translucent pieces. In finer quality, i.e., with finer fibers, it may resemble very closely the chrysoberyl variety. The cat's-eye variety of tourmaline may be confused with the quartz variety. Tiger-eye is fashioned into stones giving a coarse single cat's-eye effect, and may be dyed or bleached to a variety of colors.

PROPERTIES OF CRYSTALLINE QUARTZ. Crystalline quartz is notable for the constancy of its major properties. The refractive indices are 1.544 and 1.553 and the birefringence .009, almost without variation. Quartz crystallizes in the hexagonal system and is uniaxial positive. The specific gravity is between 2.65 and 2.66—and constant for crystalline (but not cryptocrystalline) material. Quartz has no distinct cleavage. The fracture is conchoidal, with a vitreous luster on fracture surfaces.

CRYPTOCRYSTALLINE VARIETIES. There are many gem varieties of the very fine grained or cryptocrystalline subspecies of quartz. The term chalcedony, which refers specifically to white, gray, blue-gray, and black cryptocrystalline quartz, is applied also to all varieties of the subspecies.

CHALCEDONY includes semitransparent to translucent white, gray, blue-gray, and black fine-grained quartz. Some of the white material resembles moonstone, but lacks the floating blue light that characterizes the feldspar variety and possesses a conchoidal waxy fracture in contrast to the vitreous cleavage or fracture surfaces of feldspar. Glass may resemble chalcedony in both appearance and properties but possesses a conchoidal vitreous fracture.

CARNELIAN is a low intensity red to orange and is semitransparent to translucent. It resembles jade and fire opal of similar color and is imitated by glass.

SARD is the term applied to brownish-red to red-brown translucent chalcedony. It is darker and less intense in color than carnelian. Jade, glass, and common opal may resemble sard.

CHRYSOPRASE is a semitransparent to translucent light to medium yellowish-green chalcedony. It may be confused with jadeite, jade substitutes, prase, opal, poor qualities of emerald, bowenite serpentine, and glass.

BLOODSTONE or heliotrope is a semitranslucent dark green chalcedony with brownish-red spots. There are no gem materials or imitations that resemble bloodstone closely.

Figure 125

Moss agate.

MOSS AGATE is a semitransparent to translucent white to light gray chalcedony with dendritic black or green inclusions.

AGATE is a translucent chalcedony with curved or irregular bands of different colors on different depths or transparency of the same hue. The colors are usually red, brown, white, gray, and blue-gray. The bands follow the contours of the cavity in which the agate was deposited. Although such minerals as malachite, smithsonite, and calcite may have a similar structure, only calcite (onyx marble) resembles agate.

ONYX is applied to agate-like chalcedony in which the bands are straight and parallel. The term has been used by colored stone dealers to apply to any dyed chalcedony. The colors and translucency of true onyx are similar to those of agate. Onyx marble (calcite) resembles onyx in appearance.

"Black onyx" is the term used throughout the jewelry trade for chalcedony dyed to an opaque black.

SARDONYX is onyx with alternate bands of sard or carnelian colors with white or black layers.

JASPER is an impure semitranslucent to opaque chalcedony which occurs in combinations or single colors of red, yellow, brown, dark green, or grayish-blue. Only pottery or glass imitations are likely to be confused with jasper.

PROPERTIES OF CRYPTOCRYSTALLINE QUARTZ. Unlike crystalline quartz, chalcedony does not have constant properties. The specific gravity is 2.60 (±.05). It is usually 2.60 to 2.62, but less compact material may be even lower than 2.55. The refractive indices are near 1.535 to 1.539. In monochromatic light, two readings at those points are encountered frequently, but in white light one reading is encountered in that vicinity. Chalcedony shows no cleavage. The fracture is conchoidal and the luster on fractures is dull to waxy. The luster on fracture surfaces furnishes a simple means of distinguishing from glass. The hardness is just under 7.

Rhodizite is a very rare mineral which has been fashioned as a gemstone for collectors. In gem quality it is a transparent colorless, light yellow, and light yellowish-green material. It is also known in a light red translucent variety.

Rhodizite crystallizes in the cubic system. Its refractive index is 1.69 and specific gravity 3.40. The hardness is 8. It is identified by its isotropic character and 1.69 refractive index. While glass may have the same properties otherwise, the hardness and inclusions of rhodizite distinguish it.

Rhodochrosite, the manganese-carbonate member of the calcite mineral group, occurs both in light red transparent crystals and in a red and almost white agatelike structure. Its major use is for carvings and other ornamental objects in the nontransparent form, but some transparent material is faceted for collectors. It has rhombohedral cleavage; indices of 1.597 and 1.817; a hardness of 3.5 to 4.5; the specific gravity is about 3.7 for crystals, and slightly lower for massive, agatelike material. It is negative in sign. Rhodochrosite effervesces strongly to hydrochloric acid.

Rhodonite is a light to medium violetish-red (flesh-red) manganese silicate used mostly for ornamental objects. The semitranslucent to semitransparent stone usually contains black inclusions. Rhodonite is resembled only by coral among gemstones.

Rhodonite crystallizes in the triclinic system and has two perfect cleavages inclined at 92½° to each other. In massive form, however, it is exceedingly tough. Depending upon the manganese content, the refractive indices vary from 1.72 to 1.733 for the low index and 1.73 to 1.744 for the high. The specific gravity varies from about 3.30 to 3.68. The optic character may be either positive or negative.

Rutile. Natural rutile is usually a metallic black, but sometimes red transparent material is encountered. This type has been cut occasionally for collectors. Its refractive indices are 2.616 and 2.903, the specific gravity is approximately 4.25, and the hardness is 6 to 6.5. It is usually not fully transparent.

Scapolite is the name given to a group of minerals used infrequently as gemstones. The gem qualities include transparent colorless, yellow, light red, greenish to bluish-gray, and violetish-blue.

Semitransparent scapolite may be chatoyant. The light red (pink) and whitish stones are most frequently chatoyant.

Scapolite is most frequently confused with beryl or quartz in appearance, but may resemble in appearance tourmaline, topaz, apatite, and other gemstones light in color and low in index. Although the scapolite group in nature contains minerals with refractive index and specific gravity values near quartz, the usual gem quality material is more likely to be confused with beryl in testing. However, the birefringence is much greater. The usual indices are 1.550 (±.002) to 1.572 (±.002), and the specific gravity 2.68 (±.06), with a birefringence of .022. In the unlikely event that material in the lower 1.544 to 1.556 index class is encountered, the negative optical sign of the uniaxial material serves to distinguish it from quartz. In addition, scapolite shows perfect cleavage in two directions at 90° to one another. Light yellow fluorescence is common in scapolite.

Scheelite, the most important ore of tungsten, sometimes occurs in colorless, yellow or brown transparent crystals, which may be cut for collectors. The hardness is 5 and the specific gravity is approximately 6.12. Refractive indices are 1.918 and 1.934. It occurs in the tetragonal system and has a positive sign. Scheelite fluoresces strongly in a light-blue color under short-wave ultraviolet light.

Serpentine is an alteration mineral often used as jade substitute, especially in ornamental objects. It occurs in light to dark yellowish-green to greenish-yellow colors and is translucent to semitranslucent. The verd antique variety is used for decorative wall facing and for table and counter surfaces. While common sepentine has a hardness of 2.5 to 4, williamsite, one attractive green variety (often with small black inclusions) is usually 4. and the most attractive variety, bowenite, has a hardness of 5 to 5.5. Serpentine crystallizes in the monoclinic system and it is very finely crystalline in the common massive form. The usual refractive index is 1.55 to 1.56, but indices as low as 1.49 and as high as 1.57 have been reported. The specific gravity is 2.57 (±.06) for common serpentine and williamsite and

2.6 to 2.8 for bowenite. Both bowenite and williamsite may closely resemble chrysoprase, jadeite, or nephrite. The greenish-yellow variety shows a broad absorption band in the blue at about 4600 to 4700Å. Common serpentine is sometimes dyed a jadelike color.

Sillimanite or fibrolite is a mineral which occurs commonly in a massive semitranslucent to opaque form sometimes used for ornamental purposes and as a substitute for jade. Rarely in a transparent to translucent form it is fashioned as a gemstone for collectors. The latter form may be chatoyant. The massive material is usually grayish-white, grayish-green, brown, or brownish-green. The transparent material is usually a grayish-blue. This variety resembles spinel, sapphire, iolite, and euclase. Sillimanite crystallizes in the orthorhombic system and has one easy cleavage. It is negative in optic sign. The refractive indices are near 1.659 and 1.680 for transparent material, but may be as low as 1.64 and 1.66, with the birefringence nearer .015 which is lower than the usual .02 for transparent material. The specific gravity is 3.24 (±.02), but may be somewhat less if massive material is not compact. The hardness is 6 to 7, and its dispersion low.

Sinhalite is a brownish-green to brown gemstone long thought to be brown peridot. Its refractive indices are 1.668 and 1.707 and the specific gravity, 3.48. It is biaxial, negative. Even in a brownish-green color, peridot has a specific gravity very close to that of pure methylene iodide. Although it usually sinks, it does so much more slowly than sinhalite. In addition, sinhalite is strongly negative in sign (beta is usually 1.697, whereas the beta reading for peridot is almost exactly at the half-way point). Sinhalite has a distinctive absorption spectrum, by which it may be distinguished from peridot readily.

Smithsonite is a zinc carbonate which occurs in a translucent to semitranslucent form in white, yellow, light green, and light blue colors. In certain colors it may resemble chrysoprase, jade, or common opal, but the blue is quite distinctive.

Smithsonite is distinctive for its agate-like structure in lovely pastel colors. The refractive indices are 1.62 to 1.85, showing the large birefringence characteristic of the carbonates. Use of a Polaroid plate with the refractometer will reveal this if the stone is correctly oriented. It has a high specific gravity—4.30, and a hardness of 5. It is uniaxial with a negative sign.

Sodalite is a dark blue semitransparent to semitranslucent mineral used frequently as a substitute for lapis lazuli. Sodalite rarely contains the pyrite that characterizes lapis-lazuli. Sodalite it is frequently veined with a white mineral giving an appearance similar to that of the lapis lazuli mined in Chile. Sodalite may be confused also with lazulite and quartz of either the natural form colored by dumortierite or the dyed chalcedonic variety.

Sodalite crystallizes in the cubic system and has no easy cleavage. It has a refractive index near 1.48. The specific gravity is usually 2.24 (±.05), but may go to 2.35, and the hardness is 5 to 6.

Sphalerite, the principal ore of zinc, is considered a gem material by collectors in the rare transparent form because of its high refractive index and tremendous dispersion. In the form in which it is cut it is usually green, greenish-brown, yellow-brown, or reddish-brown. Synthetic rutile (titania), sphene, hessonite garnet, zircon, and fancy diamonds may resemble sphalerite.

Sphalerite crystallizes in the cubic system and has a perfect cleavage. The refractive index is near 2.37, the specific gravity 4.05 (±.02), and the hardness 3.5 to 4. The dispersion far exceeds that of any common natural gemstone, being over .15 compared to diamonds .044 and the .051 of sphene. Because of its extreme fragility it requires careful handling. The hardness test should never be used on a stone suspected of being sphalerite.

Sphene (titanite) is a fairly common mineral which is rarely found in a transparent gem quality form. In the opaque form, sphene is dark brown to black. In transparent gem quality it is yellow, brown, or very rarely a fine intense green. It is characterized by a high dispersion and luster. In appearance it may be confused with sphalerite, synthetic rutile, diamond, zircon, grossularite or spessartite garnet, and possibly with other gemstones of similar color such as citrine, beryl, chrysoberyl, and topaz.

Sphene crystallizes in the monoclinic system and may show a two-directional cleavage, with a 66½° angle between cleavages. In addition a parting may be evident. The refractive indices are near 1.90 and 2.03, but a considerable variation has been recorded. The birefringence varies from .1 to .135 or more or roughly double that of zircon. Specific gravity is 3.52 (±.02), hardness 5 to 5.5, and it is biaxial negative.

Spinel is a well known transparent gemstone, known unfortunately, more for resemblance to ruby and sapphire than for its own beauty. The colors of spinel, especially in blue and red always seem less intense than their counterparts in the corundum family. The common colors of spinel include red-orange (flame spinel), light to dark orangy-red, light to dark slightly grayish-blue, greenish-blue, grayish-green, and light to dark purple to violet. Spinel is known also in yellow, and black — the latter being opaque. In its various colors, spinel may be confused with ruby, sapphire, zircon (the hyacinth or flame variety especially), amethyst, garnet, synthetic corundum and spinel, glass, and doublets.

Spinel crystallizes in the cubic system and possesses no ready cleavage. Its refractive index is usually near 1.715, but readings as low as 1.71 and as high as 1.76 have been recorded. Among gem varieties, refractive indices between 1.71 and 1.72 are considered normal. However dark blue-green material may read to 1.76 or even higher. The specific gravity is usually near 3.60, with 3.57 to 3.72 as the gem range. The high-index dark blue-green material may reach 4.0 or higher. The hardness is 8. Since synthetic spinel almost always reads 1.73 or higher in index, the refractometer reading furnishes a valuable indication as to identity. Separation of spinel from pyrope is discussed under garnet (pyrope). When part or all of the magnesium in spinel's composition is replaced by zinc, the property values increase as shown above. In a partial replacement, the result is called gahnospinel, and in the full replacement — zinc aluminum oxide — it is called gahnite. See Chapter XIII for typical absorption spectra.

Spodumene is a species occurring in the pyroxene group. Fine transparent spodumene in light red to purple colors is used most frequently as a gemstone and is known as kunzite after the late George Frederick Kunz. It occurs also in very light to medium green to yellowish-green (known as hiddenite, after the man who discovered it in North Carolina), and in a colorless to yellow color. Spodumene may be confused with topaz, tourmaline, spinel, beryl, synthetic corundum, synthetic spinel, doublets, glass, corundum, and also with emerald, peridot, chrysoberyl, and demantoid garnet.

Spodumene is biaxial with a positive sign and has refractive indices of 1.660 (±.005) to 1.676 (±.005). The specific gravity is 3.18 (±.03) and its hardness is 6 to 7. Spodumene is biaxial and optically positive. Cleavage is perfect in two directions with a 93° angle between the two directions. In addition, a platy structure in a third direction may cause easy separation. The pleochroism of kunzite is strong with near colorless and red to violet colors evident both in the dichroscope and to the naked eye as the stone is turned. Hiddenite shows bluish-green and yellow-green. The yellow variety shows definite differences in depth of yellow. Today, hiddenite is extremely rare. The largest fine stone on record is under three carats.

Staurolite is a hydrated iron-aluminum silicate, best known for its brown twin crystals in the form of crosses. Usually, it is semi-translucent to opaque, but rarely transparent brown crystals occur. Some have been cut for collectors. The key properties are its orthorhombic crystal forms, refractive indices of 1.736 and 1.746, a specific gravity of 3.65 to 3.77, and a hardness of 7 to 7.5.

Stibiotantalite is a rare pegmatite mineral, an oxide of antimony, tantalum and columbium. One locality has produced transparent yellow crystals of cuttable quality. Small numbers have been cut for collectors. Properties vary, depending on the variable ratio of tantalum to columbium. It is orthorhombic, with indices of about 2.37 and 2.45; the specific gravity is about 7.5. It is biaxial with a positive sign. Hardness is 5.

Stichtite, a semitranslucent to opaque hydrated carbonate of magnesium and chromium, occurs in an attractive light violetish-red color. It is sometimes cut in cabochon forms or carved; however. its hardness is 1.5 to 2. Refractive indices are 1.516 and 1.542, the specific gravity is 2.15 to 2.2, and it effervesces in hydrochloric acid.

Strontium Titanate. See Chapter X (Synthetic Gemstones).

Taaffeite is a newly described gemstone which has been found only in a pale red-violet transparent form. Taaffeite crystallizes in the hexagonal system. Its refractive indices are 1.719 and 1.723, and the specific gravity is about 3.61. It is negative in optic sign. Its hardness is 8.

Talc, also known as steatite or soapstone, is used principally for carved ornamental objects which are substituted for jade. For ornamental purposes semitranslucent to opaque gray, grayish to brownish-green, brown, and yellow-brown talc is used. It may be substituted for jade, but the very low hardness makes its identification very simple.

Talc occurs in the monoclinic system, but in the massive form is usually cryptocrystalline. The refractive indices are 1.54 to 1.59, but in the massive ornamental form, a single dim reading is encountered between these figures; and the specific gravity near 2.75. Since the massive varieties used for ornamental objects are usually impure, variation of gravity may be as much as 2.55 to 2.80. Talc is biaxial negative. The hardness is 1 to 2.5, so the fingernail will scratch it usually.

Thomsonite, a member of the zeolite group, is used for cabochons when it occurs in white, yellow, pink and green radial fibrous groups. It has a hardness of 5 to 5.5, a specific gravity of 2.3 to 2.4. and variable refractive indices in the 1.515 to 1.54 range, but with a birefringence range from about .006 to .012. It is a hydrated calcium-sodium-aluminum silicate.

Figure 126
Thomsonite cabochons showing the typical radial fibrous groups.

Topaz is well known to the jeweler and layman alike, but usually the stone known to them as topaz is a substitute such as quartz (citrine), or a synthetic or glass. In the past, any yellow stone was called topaz with a prefix to denote to the initiated the actual nature of the stone. Today, many stone dealers offer citrine as topaz incorrectly and reserve the term "precious topaz" for the true topaz.

Topaz occurs in a variety of colors in addition to the transparent yellow, yellow-brown, and orangy-brown colors most popular in the topaz range. The other colors include very light to almost medium red (usually but not always the result of heat-treatment), very light to light blue, very light green and violet, light greenish-yellow, and colorless.

The gemstones which may resemble topaz include quartz (citrine and rock crystal), chrysoberyl, hessonite garnet, tourmaline (especially pink, but also colorless, and yellow-brown), corundum (pink, yellow, and light blue sapphire), beryl (golden beryl, aquamarine, and morganite), spodumene (kunzite), synthetic corundum, synthetic spinel, doublets, and glass. Of the unusual materials sometimes used as gemstones, topaz may be confused with danburite, apatite, scapolite, phenakite, euclase, transparent orthoclase or labradorite, beryllonite, and brazilianite.

Topaz crystallizes in the orthorhombic system and has perfect cleavage. The refractive indices for yellow to brown, and light red stones are near 1.629 and 1.637, and for colorless, light blue, and light green stones near 1.609 and 1.617. The birefringence is nearly constant at .008. Topaz is biaxial positive, has low dispersion, and is 8 in hardness. The specific gravity is 3.52 (±.02) for yellow to brown, and light red stones, and slightly higher—3.56 (±.03) for other colors. Tourmaline and glass are the stones which closely resemble topaz in appearance and refractive index. Glass is singly refractive and tourmaline has a much lower specific gravity and much higher birefringence. The unusual stones of similar index, namely andalusite, apatite, brazilianite, and danburite, are not close to topaz in specific gravity. Topaz is rather more pleochroic than might be anticipated in a gemstone usually so light in tone. Yellow topaz exhibits distinct trichroism—brownish-yellow, yellow, and orange-yellow. Blue topaz exhibits weak to distinct dichroism, depending on the depth of blue—colorless and light blue. Red topaz shows distinct to strong dichroism—light red and yellow.

Tourmaline is a gemstone noted for the large number of colors in which it occurs. These include light to dark red to purple and brownish variations of these hues, also light to dark green, yellowish-green, greenish-yellow, brown, greenish-brown, colorless, black, light to dark blue, yellow-brown, and brownish-orange. In addition, tourmaline with two colors in the same stone (usually red and green) is not uncommon. In gem quality it is usually transparent, but opaque black tourmaline is used occasionally for jewelry purposes. Chatoyant tourmaline is encountered occasionally. Since tourmaline occurs in such a wide range of tones and intensities of so many hues, there are many transparent gemstones likely to be confused in appearance with one or more varieties of tourmaline. Fortunately, tourmaline offers little difficulty in identification by the basic instruments.

Tourmaline crystallizes in the hexagonal system and possesses no perceptible cleavage. The refractive indices are 1.624 (±.005) and 1.644 (±.006), with the birefringence usually near .020. Very dark stones (especially black) may give higher readings and higher birefringence. Since tourmaline is uniaxial and negative in sign, the high reading (numerically) is constant, and the lower variable. The specific gravity may be stated generally as 3.06 (±.05), with the light red stones on the low side of this range, the blue on the high side, and black tourmaline above the upper limit of transparent gem tourmaline. Tourmaline is noted for its strong dichroism. Dark green stones show very dark brownish-green and lighter yellow-green colors. Lighter green stones, heat-treated to remove the murky greenish-brown, show weaker dichroism of blue-green to yellow-green colors. Blue tourmaline (usually greenish-blue) shows dark and light blue dichroism, with the dark blue tending toward the greenish. Brown tourmaline shows very dark brown and light greenish-brown as dichroic colors. The two colors seen in red tourmaline are dark red and light red. All dichroic colors may vary somewhat from those described, depending on the depth of color of the gemstone. See Chapter XIII, for typical absorption spectra.

Tourmaline has low dispersion and a hardness of 7 to 7.5. It is easily identified by its strong birefringence and uniaxial negative character on the refractometer. Topaz, andalusite, danburite, and apatite all have much lower birefringence.

Turquoise is a semitranslucent to opaque intense light blue in finest gem quality, tending toward yellowish-green in poor quality. In many cases, as fine blue turquoise is worn it tends to assume a greenish-blue color. Glass imitations in excellent simulation of turquoise both in appearance and physical properties often cause difficulty in identification. Of natural substitutes, variscite resembles poor quality green turquoise and chrysocolla, a copper silicate resembles blue turquoise. The latter is too soft (2 to 4) and fragile to become an important substitute. Both powdered turquoise and various mixtures of chemicals giving the same color have been bonded in plastic to imitate turquoise. That bonded in plastic has a molded appearance on the back and is cut rather than powdered by a knife blade. The hardness is much lower than that of turquoise.

The refractive indices of turquoise are near 1.61 and 1.65. Only one reading is seen on the refractometer, usually near 1.61. The specific gravity is 2.76 (—.15,+.08). Turquoise has a hardness of 5 to 6. On conchoidal fracture surfaces it has a dull to nearly waxy luster, in contrast to the vitreous luster of its glass imitation.

Plastic, paraffin, wax, oil, and most other impregnations of turquoise are detected by the use of a hot point, such as an electric needle. When the red-hot point is brought near the paraffin- or wax-impregnated turquoise, the paraffin or wax melts and runs ahead of the needle. Plastic impregnation is detected by the acrid odor of the plastic when the point is touched against the stone. Impregnated material is usually below 2.50 in specific gravity.

Figure 127
Variscite and other phosphates as seen in a section of a typical nodule.

Imitation turquoises usually contain copper compounds; therefore, a drop of hydrochloric acid quickly turns yellow when placed on the back.

Variscite or Utahlite is a semitranslucent to opaque mineral of a slightly yellowish-green color. When fashioned, it may contain yellow to greenish-yellow matrix. Variscite bears a striking resemblance to turquoise in texture and opacity, but not in color except for the poorer turquoise qualities.

Variscite crystallizes in the orthorhombic system, but is encountered in nodular masses. The refractive indices are near 1.56 and 1.59 and the specific gravity 2.50 (±.08). The luster on the rough fracture surface is dull. Variscite has a hardness of about 4 to 5.

Willemite, a zinc ore, has been fashioned as a gemstone when found in a transparent form. While cut stones are almost all of a greenish-yellow hue, it is found in green, red, and brown colors as well. In appearance it is most likely to be confused with beryl, peridot, or greenish-yellow varieties of other gemstones such as chrysoberyl.

Willemite crystallizes in the hexagonal system and has a perfect cleavage. The refractive indices are near 1.69 and 1.72 and the specific gravity near 4.00 (±.10). Willemite is uniaxial positive. Its hardness is 5.5. The willemite likely to be fashioned as a gemstone has a notably strong yellow-green fluorescence under ultraviolet radiation.

Zincite, the red oxide of zinc, in its rare occurrence in transparent crystals or grains makes a lovely gem material. It has a direction of perfect cleavage parallel to the base of the hexagonal crystal. and its hardness is only 4 to 4.5, so it is of interest primarily to collectors. It is deep red or rarely orange-yellow. The specific gravity of gem material is nearly 5.7 and the refractive indices are 2.013 and 2.029.

Zircon is notable for its distinctive beauty in a variety of colors. Best known for the colorless variety used widely as a diamond substitute, zircon is important also in the light blue color achieved by heat-treatment. Other beautiful varieties include brownish-orange, yellow, yellowish-green, brownish-green, dark red, and light red-violet. Gem quality zircon is transparent. Zircon may be confused in appearance with a number of other gemstones, including diamond, corundum, spinel, chrysoberyl, beryl, topaz, tourmaline, most of the garnet family, peridot, sphene, quartz, synthetic spinel, synthetic corundum, doublets, synthetic rutile, and glass.

Because of a tendency for zircon to break down from its tetragonal zirconium silicate structure to what is apparently monoclinic zirconia and amorphous silica, the mineral is divided into three types. Although the three types have been called alpha, beta, and gamma, and a, b, and c, it seems less confusing to refer to the types as high, medium, and low property zircons.

HIGH PROPERTY ZIRCON includes the colorless, blue, and brownish-orange zircons largely. The refractive indices are near 1.925 and 1.984. Zircon, which occurs in the tetragonal system, is uniaxial, and positive in sign. The birefringence is so strong that it may be detected by the naked eye or a low power loupe. The specific gravity is 4.70 (±.03). No easy cleavage is evident. The fracture is conchoidal, but heat-treated zircon shows a strong tendency to pit along facet edges. Since most zircon is heat-treated, this tendency to pit or crumble at the surface is common to most gem zircons. Zircon has a high dispersion, .038, or just less than diamond. The dichroism of blue zircon is strong, the colors being blue and colorless. In other varieties, dichroism is weak.

LOW PROPERTY ZIRCON occurs only in dark yellowish-green to brownish-green and green colors. The refractive indices are much lower than those of high property zircon, namely 1.810 (±.020) and 1.815 (±.020). The birefringence is very low, as shown by the figures above. The specific gravity is near 4.00 (±.07). In addition, the hardness is lower, being 6. Both low and medium property zircon are likely to exhibit a strong zonal structure similar to that caused by repeated twinning in corundum. Green zircon may be confused in appearance with demantoid, green sapphire, peridot, and chrysoberyl.

MEDIUM PROPERTY ZIRCON is that which has properties perceptibly above those of low zircon and below those of high zircon. Thus, the range between about 1.83 and 1.91 for the low or constant index and 1.84 to 1.95 or 1.96 for the high is considered medium zircon. The birefringence range for medium zircon is considered to be about .006 to .008 at the low end to about .050 near high zircon. Since the indices are above the range of the refractometer except for zircon very low in index, the gemologist seldom attempts to classify zircon carefully as to property type, although an accurate specific gravity determination permits such classification. Medium zircon is that between about 4.08 and 4.10 to about 4.55. The colors include dark red and particularly brownish-green. Medium zircon is optically positive and may show a weakly biaxial interference figure (small angle between optic axes).

Zircon presents perhaps the most widely varied group of absorption spectra among the gemstones. Almost all zircons, including colorless stones, show a strong narrow line at about 6535Å in the red and a fainter companion at 6590Å. In green, low property zircon, the main lines may be broad and smudged. Occasional red zircons show no line. Zircons from Burma and Ceylon of brown, yellow and yellow-green color often show many sharp lines (caused by uranium). See the table of typical spectra in Chapter XIII.

Zoisite, a mineral in the epidote group, has two varieties which find occasional use as gem materials, especially for ornamental objects. The light red to rose-red variety is known to mineralogists as thulite. It is semitransparent to semitranslucent. If sufficiently transparent, strong trichroism may be detected in single crystal material in yellow, light and dark violetish-red. A massive form known as saussurite is used as a substitute for jade and for ornamental objects when found in a greenish-gray to green color.

Zoisite crystallizes in the orthorhombic system and possesses excellent cleavage. It has indices near 1.700 and 1.706. The specific gravity of thulite is usually near 3.30 (±.10) and saussurite is usually lower — near 3.20 to 3.25; however, readings to 3.38 are possible. Hardness is 6 to 6.5. Saussurite is separated from jadeite by a refractive index reading by the "spot method."

Chapter XVI

A Procedure for the Identification of Gemstones and Their Substitutes

Most gemstones of unknown identity may be assumed to be one of only a few possibilities by one familiar with the appearance of the important species. If the unknown is set in a ring or other jewelry setting, the species that are cut almost exclusively for collectors are unlikely choices; as a result, the total number of likely possibilities is only about twenty-five. When the tester has classified the hue, tone and intensity of the color, he has reduced the number of species into which the stone could be fitted still further.

If the gem tester is particularly observant, he can reduce the list of possibilities to a very small number. First, he notes the color and transparency of the unknown. If it is transparent and colorless, there are many possibilities; but any hue present, whether dark or light, reduces the number either slightly or materially, depending on the hue and tone. A nontransparent stone in some colors can only be one of just a few; for example, a banded stone in two shades of green is almost surely malachite, dyed agate, dyed onyx marble, glass or plastic. Thus, the first glance noting color and transparency only has a distinct value to the gem tester.

In this first view, many other characteristics are important. The luster should give a fair idea of the refractive index range. Since luster is determined by the refractive index plus the flatness of the polished surface, the higher the luster, the higher the refractive index of the unknown. Is the luster metallic, submetallic, adamantine, subadamantine, vitreous, subvitreous, waxy, greasy, silky, or dull? The first three categories surely reflect the presence of indices over the refractometer scale. Subadamantine suggests an index range high on the scale, vitreous midscale, and subvitreous low on the refractometer scale. Comparison with gems of known identity helps one to classify indices readily. Waxy and a greasy luster is usually associated with a poorly polished surface, and silky is applied to a gemstone with many needlelike inclusions.

The degree to which dispersion is evident in a transparent faceted stone provides an important clue to the identity of the unknown. Only a few gemstones and substitutes have a degree of dispersion sufficient to be obvious and noteworthy to the unaided eye; the presence or absence of fire is a significant feature. The stones that are strong in this property include synthetic rutile, strontium titanate (Fabulite), demantoid, sphene, diamond, zircon and some glass.

Is any cleavage evident? Only a few gem species, such as diamond, topaz, spodumene and the feldspars, are likely to display obvious cleavage.

Is doubling of opposite facet junctions obvious to the unaided eye or under low magnification? Stones showing strong doubling include synthetic rutile, sphene, zircon, peridot and tourmaline, among the important gem materials.

How well is the stone polished; this may suggest its hardness range. Stones with rounded facet edges and poor polish in general are probably soft; however, synthetic corundum and other inexpensive materials are sometimes polished so rapidly that the quality of polish is inferior. The irregular fractures at the surface of synthetic corundum caused by the heat generated in too-rapid polishing are typical of that material.

In colored stones, is there an obvious pleochroism as the stone is turned? Common gemstones with sufficient pleochroism to be noted by the unaided eye include kunzite, andalusite, tourmaline, zircon, ruby, sapphire and alexandrite. Among the rarer stones, it is likely to be obvious in kornerupine, benitoite, iolite, epidote and others.

Is there a luster difference between crown and pavilion or between different portions of the crown? This is usually obvious in garnet-and-glass and other doublets or triplets with wide differences in index between parts.

What is the luster on fracture surfaces? This is particularly important in translucent and opaque materials. Most transparent stones in the middle to low index range have a vitreous luster on conchoidal fracture surfaces, as do glass imitations; however, many natural, translucent and opaque stones have granular or other types of fracture. Those with conchoidal fractures seldom have a vitreous luster. Chalcedony usually has a waxy luster on fractures and turquoise a dull luster. This provides a ready means of separating natural stones from glass with its vitreous fracture luster.

If any of the various optical phenomena are present, the number of possibilities is reduced materially. This is true of play of color, change of color under different lights, and adularescence. Weak asterism and chatoyancy are found in a number of species. In addition to the gems in which asterism is frequently seen, ruby, sapphire and quartz, there are many others in which a star is very rarely encountered. These include beryl, peridot, chrysoberyl, topaz, spinel and garnet. Beryl, demantoid, nephrite, enstatite, diopside, scapolite, kornerupine, feldspars, apatite, zircon, sillimanite and others may show a cat's-eye effect, in addition to the more familiar chrysoberyl, quartz and tourmaline.

A red ring seen near the girdle in a transparent faceted stone when it is turned table down on a white surface suggests a garnet-top doublet. Flashes of red color from a deep, vivid-blue stone suggests synthetic spinel.

There are many more characteristics that assist the tester in narrowing the number of possibilities an unknown stone could be.

Having noted the characteristics that are obvious to the unaided eye or by using a low power loupe, the next step in this elimination system, is to determine the refractive index or indices of the unknown. This determination, if done in monochromatic light or with a red Wratten A filter, often eliminates all but one gemstone. At other times, only two or three possibilities remain on the basis of the refractive index determination.

The procedure from this point on depends on the findings made with the refractometer. The next step is chosen to most effectively separate the remaining possibilities left after the refractive index test. This is indicated for each group of possibilities determined on the basis first of color and then refractive index range in the next eleven chapters.

For example, suppose a transparent yellow gem proves to be above the limits of the refractometer in refractive index. There are several possibilities that the unknown could be. The most likely, perhaps, are diamond, zircon and synthetic rutile. However, the diamond could be naturally colored or colored by irradiation and heat treatment. In addition, a diamond doublet is a possibility and, although exceedingly unlikely, glass could have an index above the refractometer limits as well as the garnet top of a garnet-and-glass doublet.

There are several things to determine, each successive step indicated by the results of the previous one. Perhaps the first information needed is whether it is singly or doubly refractive. This could be determined by polariscope, but, since we also need to know some of the characteristics to be seen under magnification, and both zircon and synthetic rutile have exceedingly high birefringence, a condition easily recognized in transparent materials under magnification, the use of a magnifier seems to be the next logical step. If strong doubling of opposite facet edges is seen and the stone has natural inclusions, zircon would be identified because synthetic rutile is eliminated. As another possible advantage a doublet could be detected under magnification or, if bubbles were seen in a stone with no doubling, glass would be identified. If the stone proved to be a diamond, only the spectroscope would be satisfactory for distinguishing between naturally and artificially colored material.

If the stone were doubly refractive and no inclusions were visible, specific gravity, strength of doubling, or strength of dispersion could distinguish between high property zircon and synthetic rutile, or immersion in methylene iodide would show up the great difference in index by the great difference in relief. Thus, the number of tests depends on the findings of each of the tests as taken. Therefore, with an unknown yellow transparent stone, one or two tests may suffice or it may be necessary to take half a dozen.

In each of the succeeding chapters, the identification of the gemstones occurring in one or two colors is discussed, and the means by which accurate determinations may be made following the refractive index determination. Seven chapters on transparent gem materials are presented first, and then four on nontransparent stones.

Chapter XVII

The Identification of Transparent Purple and Violet Gemstones and Their Substitutes

Although several other stones have been listed, the indisputably deep-colored purple or violet gems include amethyst, almandite or rhodolite garnet, amethystine sapphire, spinel and tourmaline; and in light colors, kunzite, morganite beryl, topaz and their substitutes. The others listed are borderline in color or rarely encountered in gem use.

First Test. Clean the stone and examine it with the unaided eye or a low power loupe, to detect any identifying characteristics. In addition, note its luster, degree of dispersion, whether doubling of opposite facet edges is visible, if there is any obvious dichroism or cleavage, and whether any of the several optical phenomena are present. Observations made initially may enable the gemologist to confirm a probable identity with just a test or two. If, in this preliminary examination, any of the following properties or conditions are noted, the probabilities include the following:

Molded back facets prove the unknown to be a glass or plastic imitation. (See Chapter XI.)

A luster difference between crown and pavilion or between table and the lower crown facets suggests a doublet.

Distinct color change from daylight to artificial light indicates chrysoberyl (alexandrite), sapphire, and synthetic alexandrite-like sapphire or spinel.

Figure 128

Unpolished concave pavilion facets, proving molding.

Warmth to the touch (compared to the cold feel of crystalline materials) is a property of amorphous materials such as glass and plastic imitations.

Adamantine luster suggests diamond.

A visible separation plane indicates a doublet or triplet.

Second Test. After an initial inspection and classification of the unknown's color and its obvious characteristics, take a refractive

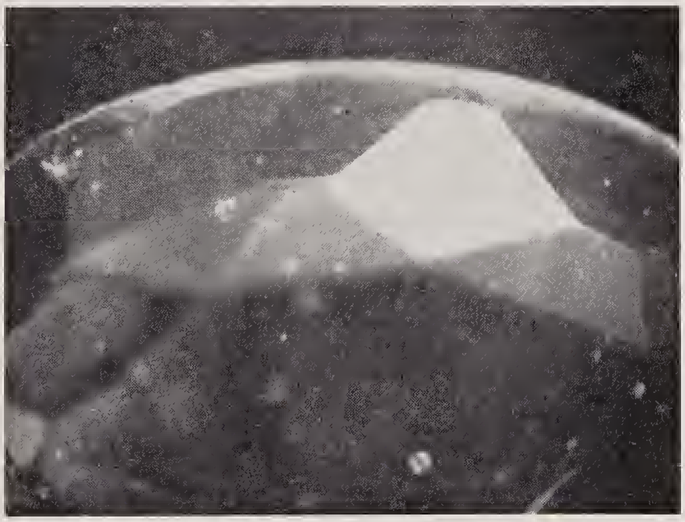

Figure 129

Difference in luster between garnet cap and glass lower crown and pavilion of a garnet-and-glass doublet.

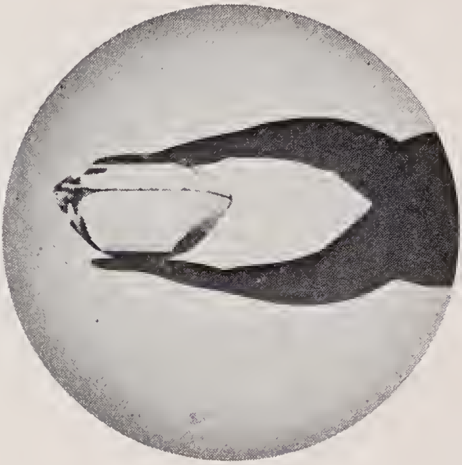

Figure 130

Cement layer on a triplet immersed in water.

index reading. If the stone has a well-polished flat facet, use the normal refractometer method. If no reading is seen and the shadow area fails to extend to the liquid line, at 1.81 (which would show that the index is over the instrument's upper limit), try the spot method.

It should be possible either to obtain a reading or to determine that the index is over the limits of the refractometer on any flat or convex polished surface, unless it is mounted in a manner that makes contact with the hemisphere impossible or unless a surface film prevents optical contact. If refractometer findings are unsatisfactory, immersion in liquids of known index should yield an approximation of the index. (See Chapter V.) If no approximation of index seems possible, magnification, polariscope, dichroscope and spectroscope findings may serve to identify the material without a refractive index determination. In rare instances, removal of the gemstone from the mounting for better magnification or for a specific gravity test may be needed. Refractive indices are given in the following table and other properties in a second table near the end of this section.

Refractive Indices*

Diamond		2.417	
Zircon (high, med.)	1.925		1.984
Almandite		1.80	
Corundum	1.762		1.770
Syn. corundum	1.762		1.770
Rhodolite		1.76	
Chrysoberyl	1.746	1.747	1.755
Syn. spinel		1.73	
Spinel		1.718	
Spodumene	1.660	1.666	1.676
Tourmaline	1.624		1.644
Topaz	1.629	1.631	1.637
Beryl	1.585		1.594
Quartz	1.544		1.553
Plastics			
Celluloid		1.49 to 1.52	
Plexiglas and lucite		1.50	
Bakelite		1.55 to 1.67	
Polystyrene		1.59 to 1.67	
Glass (normal range)		1.48 to 1.70	
Glass (extreme range of gem imitation types)		1.44 to 1.77	

*A single figure is given for isotropic, two for uniaxial, and three for biaxial materials. Variations are shown in the refractive index tables in the Appendix.

If the scale is shadowed all the way to the liquid line, at 1.81, showing the index of the stone to be above the limits of the refractometer, there are only four possibilities: diamond, zircon, almandite garnet or a garnet-and-glass doublet. Of these, only zircon is doubly refractive, so that doubling of opposite facet edges seen under magnification in a stone with an index greater than 1.81 would prove it to be zircon. With the exception of X-ray treated stones, zircon is never violet and rarely purple. A garnet red is usually more descriptive of reddish zircon than is purple, but some zircon is likely to be classified in this color category.

A violet diamond is unusual but not exceedingly rare; it is likely to be very lightly tinted. The brilliancy, fire, sharp facet edges, high luster and characteristic girdle surface produced by lathe-turning identify diamond. Naturals on or near the girdle, cleavage, and crystal inclusions also are typical.

On the other hand, almandite garnet or garnet-and-glass doublets in a purple color are usually deeply colored. Almandite rarely has a refractive index above 1.80; usually, a figure in the vicinity of 1.78 or 1.79 is obtained. Since the garnet in a garnet-and-glass doublet is almandite, this applies to doublets as well. It is relatively simple to distinguish between almandite and a garnet-and-glass doublet on the basis of the appearance under magnification. The doublet shows a difference in luster on the crown between the thin cap of almandite and the lower portion of glass, in most cases, or between crown and pavilion, if the plane of separation is at the girdle. This difference can be obvious to the unaided eye after it has been observed several times. The almandite cap usually contains needlelike or other angular inclusions, and there are bubbles in the plane of contact between the garnet and the glass.

In the next lower range of refractive indices are found sapphire, synthetic sapphire, rhodolite garnet, chrysoberyl, also almandite garnets or garnet-and-glass doublets, as indicated earlier. If seen in artificial light, alexandrite may have a slightly purplish cast, but rarely the amethystine color of synthetic alexandrite-like sapphire. Usually, the artificial light color of a good alexandrite is comparable to the color of almandite garnet. Some natural sapphires show a color change from blue in daylight to violet under incandescent light.

Under magnification the curved striae and bubbles of synthetic corundum should be visible and should identify or eliminate it as a possibility immediately. Curved striae are more prominent in synthetic alexandrite-like sapphire than in any other variety of synthetic corundum. They are usually visible directly through the table. On the other hand, angular inclusions or straight striae identify the unknown as natural. Examination under magnification of 30X, or more, also should enable a tester to determine if the doubling of opposite facet edges associated with double refraction is evident or whether it is absent. Both sapphire and the alexandrite variety of chrysoberyl have a birefringence of approximately .009, so the doubling is slight. A strong color change from green to red (or perhaps purple-red) from daylight to artificial light in alexandrite may serve to distinguish it from corundum, or synthetic corundum. If the stones are loose, specific gravity would permit a quick separation between chrysoberyl and corundum; however, this should not be necessary. Chrysoberyl is biaxial positive, with the alpha and beta indices only about .001 apart. Thus, on the refractometer it acts as if it were uniaxial with a positive sign, so one index is always evident at 1.746 or 1.747. (Such information may be gained by using monochromatic light or a filter such as a Wrattan red gelatin filter.) In contrast, corundum is negative in sign with a constant index at the high figure of almost 1.77. Thus, if the white-light index appears to be at 1.75 or below, chrysoberyl is indicated, and if the index is above 1.76, corundum is suggested.

Rhodolite, almandite, and garnet-and-glass doublets are all singly refractive. Although all may show anomalous double refraction in the polariscope, they show neither doubling nor pleochroism. Alexandrite and amethystine, or "plum," sapphire are strongly pleochroic. Should rhodolite or almandite show strong anomalous double refraction in the polariscope and also have an index near that of corundum or chrysoberyl, the dichroscope should solve the problem. The absorption spectra for these stones are distinctive, furnishing another means of ready separation.

The next lower index group includes pyrope garnet, synthetic spinel and spinel. Pyrope with any traces of purplish or violet color usually has an index near 1.75, the borderline for rhodolite. Since rhodolite is a combination of the almandite and pyrope molecules, where to draw the line between rhodolite and pyrope is more a matter of color than index. Pyrope garnet was not listed for this section, because a purple color suggests excess almandite and higher properties. At 1.728 to 1.73, synthetic spinel is consistently .01 higher in index than natural spinel, which is usually 1.718 (±.002). Synthetic spinel differs from both pyrope and spinel, in that it is characterized by a very strong anomalous double refraction, which has a cross-hatched pattern when seen under 5 or 10X between crossed Polaroids. (See Figures 89 and 90.) Of course, the synthetic may have gas bubbles with high relief, in contrast to the inclusions of pyrope, which show low relief and are often of irregular, rounded outlines. Natural spinel may be flawless, contain fingerprints made up of tiny octahedra, or it may have octahedral crystal inclusions of good size. These eight-sided crystals (shown in Figure 91) occur individually, in groups, and in sheets resembling the fingerprint inclusions of corundum. In this pattern, the octahedra may be so tiny that high magnification is needed to disclose their shape.

The next group of possibilities includes the kunzite variety of spodumene, topaz, tourmaline, glass and plastics. Spodumene has distinctly higher indices than any of the others in this group, with the exception of some glass and plastics. Its indices are 1.660 and 1.676. Spodumene has a positive sign (beta is near 1.666). In addition, it usually shows rather strong fluorescence under long-wave ultra-violet light. Its purple and colorless dichroic colors are apparent as the stone is turned.

Purple-red tourmaline has refractive indices of approximately 1.624 and 1.644, with a birefringence of approximately .020 and a specific gravity of about 3.04. It is easily separated from topaz, its fairly close companion in refractive index, by its great difference in birefringence, optic character, and specific gravity. Tourmaline floats and topaz sinks in methylene iodide, 3.32. The .008 birefringence of topaz is less than one-half that of tourmaline. Doubling of opposite facet junctions should be obvious in tourmaline under 20X. Tourmaline is usually deep in color, whereas topaz is inclined to be rather pale. Tourmaline is negative in sign, which on the refractometer means that the 1.644 index is constant and the 1.624 variable. On the other hand, topaz is biaxial and positive in sign; therefore, the lower reading varies less than does the high upon rotation of most facets on the refractometer.

The morganite variety of beryl is usually rather high in refractive index for the beryl species, with readings about 1.585 to 1.594 and, for beryl, a rather high birefiringence of .009. There is really no other gemstone very likely to be confused with beryl in this color. Quartz of the amethyst variety is typified by its 1.544 and 1.553 refractive indices. Usually, the finer the quality of amethyst, the stronger the dichroism. Strong color zoning is common in amethyst, and the so-called washboard fracture that is typical of amethyst and heat-treated citrine is another identifying characteristic.

Glasses and plastics are all singly refractive. The specific gravity of any plastic is so low that it is obvious in the form of a featherweight heft in the hand of a gemologist.

Property Table for Purple and Violet Gem Materials in Order of Descending Indices

Name	**Polar.**	**Pleo.**	**S.G.**	**Hard.**	**Additional**
Diamond	S(anom.)		3.52	10	naturals, cleavage
Zircon (high)	D	W	4.70	7.5	doubling
Zircon (med.)	D	W	4.40	7.5	doubling
Almandite	S(anom.)		4.05	7.5	spectrum
Sapphire	D	S	4.00	9	inclusions
Syn. sapphire	D	S	4.00	9	striae, bubbles
Rhodolite	S(anom.)		3.84	7-7.5	spectrum
Chrysoberyl	D	S	3.73	8.5	color change, spectrum
Syn. spinel	S(anom.)		3.64	8	bubbles
Spinel	S		3.60	8	inclusions
Spodumene	D	S	3.18	6-7	fluorescence
Tourmaline	D	S	3.04	7-7.5	spectrum, doubling
Topaz	D	D	3.53	8	pleochroic
Beryl	D	D	2.82	7.5-8	uniaxial –
Quartz	D	W-D	2.66	7	interference figure
Glass	S		2.3-4.5	5	molded?
Plastics	S(anom.)		<2.00	<3	

Among the rare gem materials sometimes cut for collectors and that may occur in a purple or violet color are apatite, axinite, fluorite, iolite, scapolite and taaffeite. The identification and description of these rarely encountered gemstones is discussed in Chapter XV, together with the means by which they are most readily separated from the stones closely resembling them. Their refractive indices and specific gravity are given in the following table:

	Refractive Indices		Specific Gravity	
Taaffeite	1.719		1.723	3.61
Axinite	1.678	1.685	1.688	3.29
Apatite	1.642		1.646	3.18
Scapolite	1.550		1.572	2.68
Iolite	1.542	1.547	1.551	2.63
Fluorite		1.434		3.18

Chapter XVIII

The Identification of Transparent Blue Gemstones and Their Substitutes

The prominent transparent blue stones include sapphire, aquamarine and zircon. This section is concerned primarily with the characteristics used to identify this trio and the means by which they may be distinguished from the gems and substitutes that may resemble them. The materials that may be confused with sapphire include synthetic sapphire, synthetic spinel, spinel, tourmaline and iolite ("water sapphire"). In light colors, both zircon and aquamarine resemble sapphire. Zircon could be confused with synthetic rutile (not commonly available in this color), diamond, pale-blue sapphire and both synthetic spinel and sapphire. Aquamarine could easily be confused with blue topaz, light-blue tourmaline, the rare stones, apatite and euclase, as well as light-colored synthetic spinel and synthetic corundum. Glass plus doublets, triplets and foil backs could be confused with any of these stones.

First Test. Clean the stone and examine it with the unaided eye or a low power loupe, to observe its characteristics. In addition, note the luster, degree of dispersion, whether doubling of opposite facet edges is visible, if there is any obvious dichroism or cleavage, and whether any of the several optical phenomena are present. Observations made initially may enable the gemologist to confirm a probable identity with only a test or two. If, in this preliminary examination, any of the following properties or conditions are noted, the probabilities include the following:

Strong dispersion suggests diamonds, zircon, or synthetic rutile.

Adamantine luster suggests diamond or synthetic rutile.

Doubling of opposite facet edges is often visible to the unaided eye in a large zircon or synthetic rutile.

A visible separation plane indicates a doublet or triplet.

A molded appearance on back facets proves the unknown to be a glass or plastic imitation. (See Chapter XI.)

A coated back on a star stone suggests a star quartz or synthetic foil back.

An exceedingly low specific gravity is often noticeable in plastic imitations, when a large stone is hefted.

Warmth to the touch (compared to the cold feel of crystalline materials) is a property of amorphous materials such as glass and plastic imitations.

A luster difference between crown and pavilion or between table and the lower crown facets suggests a doublet.

Flashes of red from a dark sapphire-blue gem suggest synthetic spinel.

A six-rayed star in reflected light indicates star sapphire, synthetic star sapphire. or a foil back.

Figure 131

Doubling of opposite facet edges in a synthetic rutile.

Second Test. The possibilities may be narrowed to a few at most, if the stone is well enough polished to give a reading on the refractometer. If no regular reading is obtained on a flat facet, or on a curved surface by the spot method, determine whether the scale remains dark up to the refractive index of the contact liquid, at 1.81. If the stone has a flat facet, yet the spot does not stay dark all of the way up the scale, it is possible that a film is obscuring the reading. If the manner of setting does not permit a surface to be brought into contact with the refractometer, the unknown probably can be identified by some of the other tests described. If necessary to gain a closer approximation of refractive index than that provided by an estimate of luster, try one of the other methods discussed in Chapter V.

REFRACTIVE INDICES*

Synthetic rutile	2.616		2.903
Diamond		2.417	
Zircon (high)	1.925		1.984
Corundum	1.762		1.770
Syn. corundum	1.762		1.770
Syn. spinel		1.728	
Spinel		1.718	
Tourmaline	1.624		1.644
Topaz	1.609	1.611	1.617
Beryl	1.577		1.583
Quartz (dyed)	1.544		1.553
Iolite	1.542	1.547	1.551
Plastics			
Celluloid		1.49 to 1.52	
Plexiglas and lucite		1.50	
Bakelite		1.55 to 1.67	
Polystyrene		1.59 to 1.67	
Glass (normal range)		1.48 to 1.70	
Glass (extreme range of gem imitation types)		1.44 to 1.77	
Opal		1.45	

*A single figure is given for isotropic, two for uniaxial, and three for biaxial materials. Variations are shown in the refractive index tables in the Appendix.

If the reading is above the scale, the only possibilities are zircon, diamond. synthetic rutile and garnet-and-glass doublets. Although glass of the type used in refractometer hemispheres could be higher, it is not used commercially for a gem substitute, since it is much too soft.

Zircon and synthetic rutile both have very strong birefringence, but that of synthetic rutile is five times that of zircon. The dispersion of synthetic rutile is even greater relative to zircon — almost nine times as great, but in dark blue synthetics it is subdued somewhat. Zircon often shows a distinct absorption line at 6535Å and a weaker companion at 6590, whereas synthetic rutile shows no absorption line in the red. Blue zircon has a specific gravity of 4.70(±.03), in contrast to the approximately 4.26 of synthetic rutile. Blue zircon is strongly dichroic, with one direction a rich blue and the other colorless or yellowish. Zircon's color is sometimes intensified greatly by coating the pavilion apparently with a fluoride layer. It is recognized by the obvious iridescent sheen imparted. It may be removed by boiling in concentrated sulphuric acid. Rutile's dichroism is weak. The blue synthetic rutile is apparently not always available from the usual commercial sources.

Diamond is singly refractive and may be distinguished by this means from both synthetic rutile and zircon, the only other blue stones with which it is at all likely to be confused in appearance. Diamond with a natural blue color may be distinguished from that which has been subjected to electron irradiation by use of a conductometer; natural blue diamond (type IIb) conducts current, in contrast to an irradiated blue stone that does not. General Electric has been successful in fusing boron into diamonds, giving the stones a blue color and making them electrically conductive. This has not been done commercially at this writing.

Diamonds colored blue by electron irradiation have their color confined to within about one-half millimeter of the surface. Thus strong zonal coloring, with the color zones only slightly beneath the surface and parallel to the facets, as in early cyclotron irradiated stones, plus its lack of conductivity, identify irradiated blue diamonds.

In the unusual case that the almandite garnet cap on a garnet-and-glass doublet has an index over 1.81, it would give no reading on the refractometer; it would be easily detected by magnification by examination with the unknown immersed in a suitable liquid, by the luster difference between parts, or by the red-ring test.

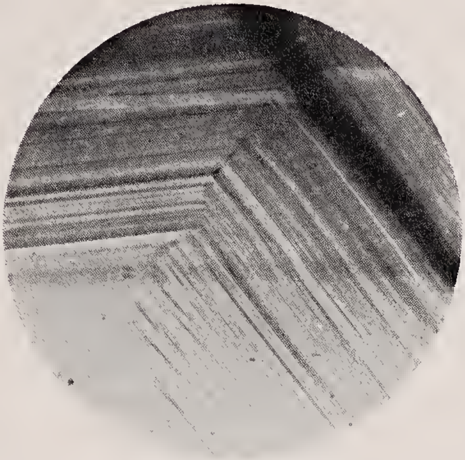

Figure 132
Straight banding at 60° in natural sapphire.

In the 1.75 to 1.77 range, the only important possibilities are sapphire, synthetic sapphire, and doublets. Dark violetish-blue and light greenish-blue are the expected dichroic colors for sapphire and synthetic sapphire. They have a specific gravity of approximately 4.0. Under short-wave ultra-violet light, synthetic blue sapphire appears to be smudged faintly with greenish-yellow. Only the very dark blue sapphire from Thailand is likely to show a similar effect. Some natural blue sapphires show a color change from blue in daylight to violet under incandescent light.

Synthetic sapphire may be distinguished from the natural by magnification. If the stone is entirely without flaws and no color banding is discovered (an unlikely eventuality, except in Montana stones), the stones may be separated either by short-wave ultraviolet in a dark room or by the spectroscope. Natural blue sapphires from most sources show a distinct to strong absorption zone in the spectroscope, in contrast to the synthetic, in which there is none. Natural blue sapphires from Australia usually show strong bands at 4500 and 4600Å that almost merge, and a separate narrower line at about 4700Å. All three lines are usually seen in Montana and Thailand sapphires, but they are not as strong as in Australian stones. In Burma and Kashmir sapphires, often only the 4500 line is visible. In some Ceylon stones it is only very faintly seen (it may be necessary to locate the optic axis direction in the polariscope, since the line is best seen when observed by transmitted light in that direction).

Synthetic and natural blue sapphire offer more means of separation than almost any other color variety in which natural corundum is reasonably well duplicated in appearance by the synthetic. Color banding is likely to be prominent in both and to be quickly revealed when viewed against a light background. The straight, parallel hexagonal banding of the natural distinguishes it from either the curved color banding or curved striae of the synthetic. The curved banding of the synthetic is often obvious to the unaided eye when a synthetic is placed over a white background. If the stone is immersed in a translucent white jar, placed over a light and examined under magnification from several directions, curved banding should be found in synthetic sapphire. Spherical gas bubbles are usually but not always present in the synthetic, and "silk" and "fingerprint" inclusions are characteristic of the natural. The synthetic fluoresces so weakly under short-wave ultra-violet that it must be examined in a completely dark room over a black background. Since it is often very difficult to see and some naturals show it very, very weakly, it is unwise for an inexperienced tester to call a sapphire natural without corroborating evidence. Star sapphires, plus synthetic and imitation stars, are discussed in Chapters X, XXIV, and XXVI.

Synthetic spinel and spinel, with refractive indices in the low 1.70 range, should be easily distinguished from any other blue stones by the fact that they are singly refractive. (We have never encountered a glass imitation in a blue color over 1.69 in index. However, if one were made, it would have a very high specific gravity — well over the 3.64 of synthetic spinel.) In addition to these two possibilities, are triplets made of two parts of synthetic spinel and blue cement, giving the stone either an appearance of sapphire or aquamarine; they are easily distinguished by immersion or under magnification. Synthetic and natural spinel are distinguished by the fact that the index of the natural is usually just under 1.72 and the synthetic is approximately .01 higher. Occa-

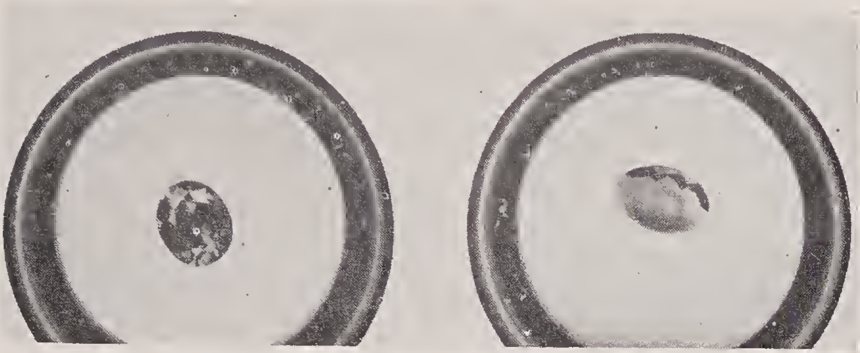

Figure 133a *Figure 133b*

A synthetic sapphire photographed in air (a) and immersed (b).

sionally, gahnospinel in a blue color may reach 1.76 in index, but this is an exceedingly rare stone. Usually, dark-blue natural spinel is a grayish-blue, in contrast to a more intense violetish-blue of the synthetic. The rich blue of the cobalt colored synthetic is more reminiscent of sapphire than it is either of natural blue spinel or synthetic sapphire. The cobalt oxide coloring agent gives rise to red flashes reflected from this otherwise excellent imitation of fine sapphire. Both this substitute for sapphire and the lighter blue that so closely resembles aquamarine is characterized by a strong red color through the emerald filter; natural spinel does not assume a comparable appearance through the filter. Natural blue spinel may appear red, but other methods, such as refractometer, spectroscope and polariscope, suffice to detect the synthetic.

There should be no difficulty in distinguishing topaz from tourmaline, since topaz has a birefringence of .008, compared to approximately .020 of tourmaline; it is positive in sign, whereas tourmaline is negative. If the stone is unmounted, dropping it in methylene iodide will distinguish between topaz and tourmaline immediately, since topaz (3.56) sinks and tourmaline (3.08) floats. Glass may have an index in the topaz-tourmaline range, but the polariscope permits an easy separation from either because of the single refraction of glass. Blue topaz is low in index (1.609 to 1.617), so there should be no difficulty in distinguishing it from tourmaline on the refractometer. Blue tourmaline is usually, but not always, dark and tends toward a greenish color, whereas topaz is more reminiscent of aquamarine. Although rarely necessary for this separation, the difference in optic character may be determined by polariscope.

Aquamarine is easily distinguished from other gemstones by a refractive index reading and from substitutes by magnification and polariscope. Synthetic spinel and sapphire, triplets, doublets, glass and plastics are the substitutes made to imitate aquamarine. All of these, with the exception of synthetic sapphire and a rare triplet made of two parts of beryl or quartz with an aquamarine-colored cement, are singly refractive.

Very rarely, quartz is dyed blue. Dye is usually readily detectable on the back of the stone, most often in the pits or cracks of a very rough back surface, or throughout if the stone has been crackled by quenching in blue dye.

Iolite is distinguished without difficulty from dyed quartz or glass by its very strong trichroism (colorless to light yellow, blue, and dark blue-violet). The indices, birefringence and specific gravity of iolite are very close to those of quartz. Plastics are separated easily by their very low specific gravity, both to heft in the hand and in a heavy liquid.

Property Table for Blue Gem Materials in Order of Descending Indices

Name	Polar.	Pleo.	S.G.	Hard.	Additional
Syn. rutile	D	W	4.26	6-6.5	doubling, fire
Diamond	S(anom.)		3.52	10	girdle, cleavage
Zircon (high)	D	S	4.70	7.5	doubling, pleochroic
Corundum	D	S	4.00	9	inclusions, spectrum
Syn. corundum	D	S	4.00	9	inclusions, flourescence
Syn. spinel	S(anom.)		3.64	8	strain pattern
Spinel	S		3.60	8	spectrum
Tourmaline	D	S	3.08	7-7.5	pleochroic, doubling
Topaz	D	D	3.56	8	cleavage
Beryl	D	D	2.71	7.5-8	inclusions
Quartz (dyed)	D		2.66	7	dye obvious
Iolite	D	S	2.63	7	strong pleochroism
Glass	S(anom.)		2.3 to 4.5	5	molded?
Plastic	S(anom.)		<2	<3	light, soft

Identification of Transparent Blue Gemstones

There are a number of gem materials that are either too rare as minerals or too rarely found in a cuttable quality to be important gemstones from a jeweler's viewpoint.

Benitoite, a mineral found only in one locality, has properties that make it an excellent gemstone, since it is 6 to 6½ in hardness and has a deep blue color reminiscent of sapphire. Kyanite is a relatively common mineral, but it seldom occurs in the exceedingly attractive sapphire blue in which it is valued as a gemstone. Kornerupine is a rare mineral that is better known in a brown or green color than in blue. However, so-called sea-green color is on the borderline of blue and some stones have almost an aquamarine color. Sillimanite or fibrolite, occurs in grayish-blue crystals that are sometimes faceted or cut *en cabochon* to display a cat's-eye effect. Light blue euclase resembles aquamarine as does some apatite, although blue apatite often has a slightly darker blue color than euclase.

Lazulite is better known in a form resembling lapis than in a transparent form. However, very rarely, transparent lazulite crystals are found which yield magnificent blue stones with a color quite unlike that of any other gem material. It is a very intense blue with a slight greenish tint. Fluorite, otherwise known as "bluejohn," is rarely faceted because of its excellent cleavage and low hardness, but it is often carved. A brief table of the principle properties of these rarer stones is given below. All are described more fully in Chapter XV.

	Refractive Indices			**Specific Gravity**
Benitoite	1.757		1.804	3.64
Kyanite	1.716	1.724	1.731	3.62
Kornerupine	1.667	1.679	1.680	3.30
Sillimanite	1.659	1.660	1.680	3.24
Euclase	1.654	1.657	1.673	3.10
Apatite	1.642		1.646	3.18
Lazulite	1.612	1.634	1.643	3.09
Fluorite		1.434		3.18

Chapter XIX

The Identification of Transparent Green Gemstones and Their Substitutes

Of the transparent green stones used in jewelry, emerald, demantoid garnet, peridot and tourmaline are important in their own right, and the others are either used mostly as substitutes or are relatively rare. In its finest quality, there is really no gemstone with a comparable color to that of emerald, with the possible exception of the Imperial grade of jadeite, the only quality that could reasonably be included in transparent category, for the finest is as transparent as a Kashmir sapphire. Of the other natural stones, a top quality demantoid approaches a fine emerald in color. Synthetic emerald, triplets, garnet-and-glass doublets and glass may all approach the color of fine emerald. Very rarely, heat-treated tourmaline from Africa is fairly close, as is the rare hiddenite variety of spodumene. The usual green tourmaline, green zircon, treated diamond and spinel are darker and less intense in color than most emeralds. Most of the others are lighter or more yellowish-green.

First Test. Clean the stone and examine it with the unaided eye or low power loupe to detect any identifying characteristics. In addition, note its luster, degree of dispersion, whether doubling of opposite facet edges is visible, if there is any obvious dichroism or cleavage, and whether any of the several optical phenomena are present. Observations made initially may enable the gemologist to confirm a probable identity with a single test. If, in this preliminary examination, any of the following properties or conditions are noted, the probabilities include the following:

An exceedingly low specific gravity is often noticeable in plastic imitations, when a large stone is hefted.

Warmth to the touch (compared to the cold feel of crystalline materials) suggests glass or plastic.

A lustre difference between crown and pavilion or between table and the lower crown facets suggests a doublet or triplet.

Strong dispersion suggests andradite garnet (demantoid), sphene, synthetic rutile, or diamond.

Adamantine luster suggests diamond.

A visible separation plane indicates a doublet or triplet.

Molded back facets prove the unknown to be a glass or plastic imitation. (See Chapter XI.)

A red ring around the girdle when the gem is placed table down on a white background suggests a garnet-and-glass doublet.

A distinct color change from daylight to artificial light indicates alexandrite, or either synthetic alexandrite-like spinel or corundum.

Chatoyancy suggests chrysoberyl, quartz, tourmaline, or glass.

Double images of opposite facet edges may be visible to the unaided eye in sphene, zircon, peridot, or synthetic rutile.

Second Test. Use the refractometer to take a refractive index reading. If the unknown has a flat polished facet, make a normal reading. If it has only curved polished surfaces, use the spot method. (Remember that the spot should not be more than 2 to 3 scale dimensions in diameter.) If it is not possible to use a refractometer because of the position of the stone in a mounting, or if no refractometer is available, it may be necessary to use one of the other methods for the determination of refractive index described in Chapter V. If no reading is seen on the refractometer, determine whether the shadow edge extends all of the way to the liquid reading, at 1.81. Any stone with a polished surface should either give a reading or be demonstrably above the limits of the instrument in index. Glass and some emeralds occasionally have a surface film that masks a reading. Rubbing the unknown by hand for a moment with rouge or cerium-oxide powder against a piece of paper or cloth on a flat surface should remove the film well enough to permit a reading. If no index is obtained by any method, proceed to other tests.

Refractive Indices*

Syn. rutile	2.616		2.903
Diamond		2.417	
Sphene	1.900	1.907	2.034
Andradite garnet		1.885	
Zircon (med.)	1.925		1.984
Zircon (low)	1.810		1.815
Corundum	1.762		1.770
Syn. corundum	1.762		1.770
Chrysoberyl	1.746	1.747	1.755
Syn. spinel		1.730	
Spinel		1.718	
Peridot	1.654	1.672	1.690
Spodumene	1.660	1.666	1.676
Jadeite	1.654	1.659	1.667
Andalusite	1.634	1.639	1.643
Tourmaline	1.624		1.644
Topaz	1.609	1.611	1.617
Beryl	1.577		1.583
Syn. emerald (Linde)	1.575		1.581
Syn. emerald (Chatham)	1.561		1.565
Quartz	1.544		1.553
Chalcedony	1.535		1.539
Plastics			
Celluloid		1.49 to 1.52	
Plexiglas and lucite		1.50	
Bakelite		1.55 to 1.67	
Polystyrene		1.59 to 1.67	
Glass (normal range)		1.48 to 1.70	
Glass (extreme range of gem imitation types)		1.44 to 1.77	

* A single figure is given for isotropic, two for uniaxial, and three for biaxial materials. Variations are shown in the refractive index tables in the Appendix.

If the index is determined to be above the limits of the refractometer (i.e., greater than 1.81), there are several possibilities that occur in a green hue. Included are synthetic rutile, diamond (either treated or natural) and zircon of both the low and medium property type. Of these stones synthetic rutile and sphene, both rather uncommon in a green color, are characterized by enormous birefringence.

Synthetic rutile has unparalleled dispersion (.330 B to G) but sphene (.051 B to G), too, is a more dispersive gem material than diamond. If an interference figure can be obtained in the polariscope, it is simple to distinguish between the two, because sphene is biaxial and synthetic rutile is uniaxial. Synthetic rutile has a 4.26 specific gravity, compared to the 3.52 figure for sphene.

In 1914, Sir William Bragg, the eminent British scientist, subjected a diamond to the radioactive emanations of a radium salt. The result was a green color and a high degree of residual radioactivity in the treated stone. Since that time, two other means of green coloration of diamonds, the cyclotron and a nuclear reactor, have been used.

No great number of diamonds were colored by radium, probably because of the danger that its continuing radioactivity would pose to wearer. Those so treated are readily identified in two ways. Placed on a covered photographic film and left for 24 hours or more, the radioactivity exposes the film through the opaque paper shielding the film from visible light. Unique inclusions provide a more rapid means of detection. The radium-treated diamond contains round, disclike brown inclusions; usually, they are numerous.

Diamonds colored by bombardment of subatomic particles in a cyclotron, or in a nuclear reactor are usually more difficult to detect.

On the basis of the examination of only a small number of natural greens, the impression has been gained that natural green diamond usually has its color confined fairly close to the surface, and is characterized by a sharp line on the spectroscope at 5040Å. The 4980, if present, is much weaker. The treated stone usually has both a 4980 and a 5040 line, of which the former is usually stronger. Neither stone has a color close to emerald green, but each is usually a low-intensity yellowish-green to blue-green. The treated stone may show the "cloverleaf" or "umbrella" effect near the culet or strong color zoning that is parallel to the facets, although this is less and less common, since most are neutron bombarded. Like synthetic rutile and sphene, diamond is strongly dispersive (.044 B to G), but unlike the other pair it is singly refractive and its excellent polish is evident in the form of very sharp edges, compared to any colored stone. The nature of the girdle on a round diamond brilliant with its lathe-turned surface is different from that of colored stones. Naturals are frequently evident, and on them trigons or parallel grooves that, if present, distinguish the diamond from any other gemstone.

The demantoid variety of andradite garnet, which ranges from intense rich green to dull yellowish-green in color is characterized by the so-called horse-tail inclusions pictured on the frontispiece and in the chapter on inclusions. It, too, is a highly dispersive gemstone; in fact, the dispersion of demantoid (.057 B to G) is higher than that of either sphene or diamond. Demantoid may be identified also by its characteristic absorption spectrum. (See Chapter XIII.) It has a specific gravity of about 3.84, compared to the 3.52 of diamond and sphene.

Zircon of the low property type often does not show birefringence under magnification; however, a uniaxial figure may be obtained and the characteristic strong zonal structure of green zircon is apparent under magnification. Very strong parallel banding, similar to that caused by twinning in corundum, is always seen in low property green zircon. In addition, the low property type has a characteristic absorption spectrum, which is shown in the table of spectra in Chapter XIII. Occasionally, green zircon has refractive indices low enough to be seen just lower numerically than the liquid line, at 1.81. The minimum figure recorded has been about 1.78. On the other hand some green zircon has properties in the medium zircon range.

In the 1.72 to 1.77 range, the possibilities among important species include corundum, synthetic corundum, chrysoberyl, grossularite garnet, synthetic spinel, spinel, plus doublets and triplets. In the green synthetic sapphire, curved striae are rarely seen. Thus, if no bubbles are visible under magnification, it may be necessary to turn to the spectroscope to distinguish between synthetic and natural corundum. This test provides a certain means of separation, in that synthetic corundum shows no absorption and natural green corundum always shows iron lines at 4500 and 4600Å that almost join one another plus a separate line at 4700Å. For other methods, see Chapter X.

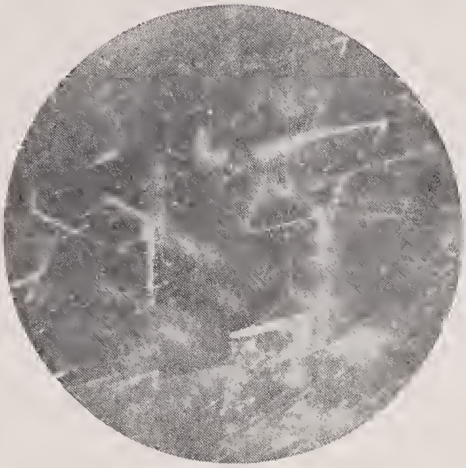

Figure 134
Metamict zircon showing diagnostic angular markings.

Green chrysoberyl varies from pale yellowish to deep brownish or bluish-green. The daylight color for alexandrite varies from a brownish or yellowish-green to a bluish-green. Chrysoberyl may be transparent and faceted, or the semitransparent to translucent cat's-eye in a cabochon form. If the green color is the daylight color of alexandrite, there should be a color change to the red of alexandrite under artificial incandescent light. In this event, strong trichroism should be present and serves to identify the stone. In addition, alexandrite has a characteristic absorption spectrum, which is shown in the table in Chapter XIII. Green material without color change shows absorption between 4400 and 4500Å, the strength of which varies with the depth of the green color.

Transparent green grossularite is exceedingly rare. In this color, the index of transparent stones is usually near 1.75. It is identified by its singly refractive character and the nature of its inclusions.

Spinel and synthetic spinel are separated effectively by characteristic inclusions, or by the difference in refractive index, coupled with the difference in the appearance of the two materials in the polariscope. A natural gem usually shows almost no anomalous double refraction, whereas synthetic spinel always shows the so-called cross-hatched double refraction, somewhat akin, at least, to that pictured in Figures 89 and 90. Synthetic spinel is characterized by gas bubbles and natural spinel by the presence of octahedra. Natural green spinel is rarely seen. When it is, it is sometimes another member of the spinel group such as gahnospinel, in which some of the magnesium is replaced by zinc; or gahnite, with all magnesium replaced by zinc. Gahnite has an index of 1.80 and a 4.55 specific gravity; and gahnospinel is between normal spinel figures and those of gahnite.

Triplets, made of an emerald-green cement joining a crown of synthetic spinel and a pavilion of the same material, are easily detected by immersion in any clear liquid. It is wise to try water or a bland oil as an immersion medium, to avoid damaging the cement.

The 1.60 range of refractive indices includes the following important gems and substitutes: peridot, spodumene, andalusite, tourmaline, topaz, glass and plastics. Peridot is readily distinguished from the others by its great birefringence, with a usual separation between the high and low indices of .036; the usual high index is about 1.690 and the low, 1.654. Peridot is unusual in that the intermediate, or beta, index (1.672) is usually exactly halfway between the high and low indices. Spodumene has indices of 1.660 to 1.676, or a birefringence of less than half of that of peridot. The beta index is 1.666, so spodumene is positive in optic sign. They are easily distinguished, in addition, by the fact that peridot either sinks very slowly or just floats in methylene iodide, whereas spodumene floats buoyantly. Spodumene in an intense green color, the hiddenite variety, is exceedingly rare; light green material is seen more often.

Andalusite in a greenish color usually shows strong dichroism that is visible even in a table-up position, with the colors a brownish-green and a dark brownish-red. A green type, colored by rare earth elements, has a brighter-green color and lacks the red dichroic color. It has a characteristic spectrum illustrated in Chapter XIII.

Green tourmaline, of course, is a common gemstone in a dark brownish-green color, but very rare in a rich medium-green resembling emerald. It is characterized by constant indices of approximately 1.624 and 1.644, with a birefringence of .018 to .020 and the high index constant. The dark green is also characterized by very strong dichroism, with one of the two windows of the dichroscope showing almost completely black and the other a yellowish-green. Rarely, green tourmaline is found in Maine and Brazil that is clear and not dark brown to almost black in the optic axis direction. Therefore, such stones do not have the blackish or brownish ends so common in the emerald-cut green tourmalines. Such stones show a dichroism of a light and a darker green.

Topaz in a light yellow-green color is rarely cut, although bluish-green to greenish-blue, resembling aquamarine, is fairly common. It has indices usually in the range of 1.609 to 1.617. It is easily distinguished from tourmaline both by its positive sign, in contrast to the negative sign of tourmaline, and by its lower indices. In addition, topaz sinks in methylene iodide, whereas tourmaline floats.

Both glass and plastic imitations with an index in the 1.60's are common. However, they are easily distinguished by the fact that they are singly refractive, in contrast to the double refraction of the other stones in the 1.60 range. Usually, their color is emerald-green, rather than a color that imitates gems with indices in the 1.60's.

In the next lower refractive index group are emerald, Chatham synthetic emerald, Linde synthetic-emerald (actually beryl with an overgrowth of synthetic emerald), heat-treated quartz, dyed chalcedony (which approaches transparency), doublets, triplets, and glass. Emerald of natural origin usually has indices in a range from 1.570 to 1.595, with a .005 birefringence at the lower end and .007 at the upper. The most important substitute for natural emerald, to date, is the Chatham synthetic.

It is apparent from the table that the only emerald source producing stones with refractive indices at all likely to be confused with those of the Chatham product is Brazil. However, Brazilian emeralds are so pale that they are unlikely to resemble the synthetic in appearance and their indices are over .005 higher than comparable Chatham figures.

Most of the important emerald sources produce stones with approximately the range of the Linde synthetic emerald (1.575 to

1.581), but the Chatham synthetic emerald is considerably lower, with indices of 1.561 to 1.564 (or 1.565). There are several other means by which Chatham synthetic emerald may be detected. Its specific gravity is almost exactly equal to that of quartz, in the 2.65 to 2.66 range. A liquid adjusted to this specific gravity, and using a Chatham synthetic and a natural emerald as indicators, provides an excellent means for quick separation, because the natural almost always sinks and the synthetic almost always floats. This is a test to be used in conjunction with other means of testing, in that the amount of platinum in a Chatham synthetic is sometimes sufficient to cause it to sink, and sometimes badly flawed natural emeralds are reduced in specific gravity by the presence of voids. Magnification would disclose whether either situation prevails.

	Refractive Indices for Emerald		**Specific Gravity**
Columbian			
Borbur	1.569	1.576	2.70
Chivor	1.571 (±.003)	1.577 (±.003)	2.70 (±.01)
Muzo	1.577 (±.003)	1.583 (±.003)	2.71 (±.01)
Brazilian	1.568 (±.002)	1.573 (±.002)	2.69 (±.01)
Russian	1.579 (±.003)	1.588 (±.003)	2.73 (±.02)
Indian, African	1.585 (±.003)	1.592 (±.003)	2.74 (±.02)
Sandawana	1.586	1.593	2.75 (±.02)
Chatham Syn.	1.561 (±.001)	1.564 (±.001)	2.66
Linde Syn.	1.575	1.581	2.71 (±.02)

The inclusions in Chatham synthetic emerald are liquid- and gas-filled spaces arranged in wisp- or veil-like patterns, an appearance so characteristic that it is easily detected and hard to confuse with the natural. Natural emeralds are characterized by three-phase inclusions: liquid, gas and tiny square, rectangular- or diamond-shaped crystals in the same space within the stone. (See Chapter VIII.) The natural is also likely to have calcite inclusions, which usually occur in planes and have a tendency to impart a granular appearance to the stone under magnification. Brass-yellow pyrite crystals, either in cubes or the twelve-faced pyritohedrons, are also common in the natural stone. Unless care is taken, however, they could be confused with metallic-white isometric crystals in the

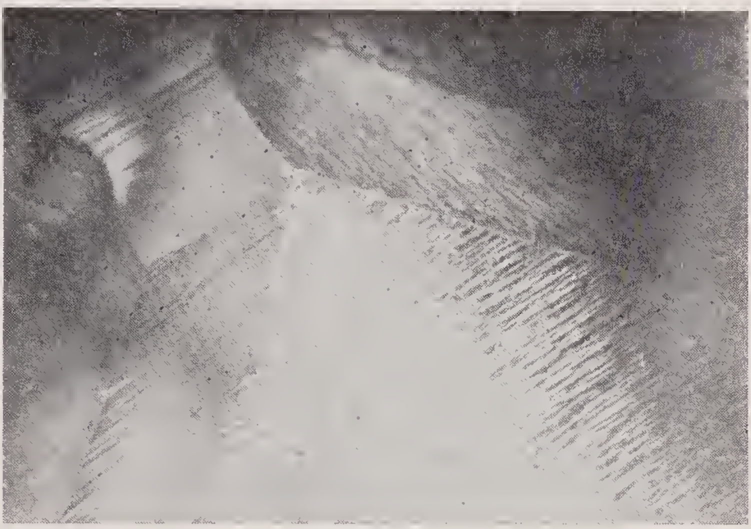

Figure 135
Magnified surface of a Linde synthetic-emerald-coated beryl showing the incipient crystal face development as the synthetic emerald is deposited on the prefaceted beryl.

Chatham synthetic. The synthetic may also include colorless crystals of phenakite.

Another test that is useful in distinguishing between Chatham synthetic and natural emeralds is fluorescence, but it must be used with great care, since it can lead the tester astray. Long-wave ultraviolet radiation causes the synthetic to fluoresce, but the fluorescence is such that it must be observed in a dark room. with the stone placed on a dull black background. Rarely, fine natural emeralds will fluoresce weakly, too, but the fluorescence does not seem to make the stone opaque, as it does in the synthetic. (See Chapter X.)

The Linde synthetic-emerald-coated beryl is easily distinguished by the fact that the overgrowth appears under magnification as an intense green layer over almost colorless material; immersion makes this even more prominent. In addition, under magnification, it will be seen that the overgrowth has not been polished on all facets; it shows a rough appearance caused by small crystal faces.

A color filter designed by Anderson and Payne before the advent of synthetic emerald was a useful. inexpensive instrument for separating emerald from most imitations. The advent of the Chatham and Linde synthetics and some new sources of natural emeralds has reduced its value in emerald use greatly. Natural emeralds from most sources, as well as Chatham and Linde synthetics, appear pink to red under the filter, depending on depth of color; however, Indian and some African emeralds appear green, as do most imitations. Green zircon and demantoid are usually pink under the filter. There are some imitations, however, that employ a cement that imparts a red color to the whole as seen under the filter, and some green plastic-coated beryl also appears red. Thus, the value of the filter in emerald identification today is very limited.

Low quality beryl beads are sometimes coated with an emerald-green plastic to give a rich-green appearance; they are easily detected by bubbles in the plastic coating under magnification. In addition, of course, they are very soft and often show a flow structure in the coating. It is obvious under magnification that they have not been polished. To the unwary, natural inclusions in the beryl inner bead could cause some difficulty.

Since emeralds are often fractured and the fractures may be visible to the unaided eye, thus seriously reducing the value of the stone, it has been a long-standing practice in the Orient and elsewhere to "oil" stones of this kind. The reason for this is that the oil, which has an index not too far from that of beryl, replaces the air in the fractures; therefore, the fractures either become invisible or much less apparent to the unaided eye. Thus, it is very important for the gem tester to be aware of this practice and to be able to detect it. Usually, the oil is colorless; sometimes, however, if a stone is pale, an emerald-green dye is added to the oil. Detection of oiling is difficult. If a stone has been treated recently, very gentle heating usually brings some of the oil to the surface where it may show up if rubbed on a fine-grain paper. It may be detectable as a liquid under magnification or as an iridescent film on the polished surface. Of course, if it drys out, its value in concealing the fractures is lost, or at least seriously reduced.

Efforts to deepen the color of pale emeralds usually consist of introducing color into the back of a wholly enclosed gypsy setting in the form of green foil, or just a green dye on or behind the pavilion facets. Such additional color may be detected by directing light through the stone to reflect from the pavilion and examining the reflected beam with a dichroscope. A tester should be able to determine by the strength of dichroism in relation to the apparent color of the stone whether an emerald has a deep natural color or whether color has been imparted by some artificial means. Coated stones are much too weakly dichroic for their depth of color.

Glass simulating emeralds tends to be given particular attention by those making imitations. It is possible to duplicate the refractive index and specific gravity of emerald very closely and to mix into the glass melt irregular fragments of a substance that will not melt

PROPERTY TABLE FOR GREEN GEM MATERIALS IN ORDER OF DESCENDING INDICES

Name	Polar.	Pleo.	S.G.	Hard.	Additional
Syn. rutile	D	W	4.26	6-6.5	rarely seen, doubling
Diamond	S(anom.)		3.52	10	girdle, cleavage
Sphene	D	D	3.52	5-5.5	doubling
Andradite	S(anom.)		3.84	6.5-7	inclusions
Zircon (med.)	D	W	4.40	7.5	doubling
Zircon (low)	D	VW	4-4.2	6	spectrum
Corundum	D	S	4.00	9	inclusions, spectrum
Syn. sapphire	D	S	4.00	9	inclusions
Chrysoberyl	D	S	3.73	8.5	pleochroic, spectrum
Syn. spinel	S(anom.)		3.64	8	strain pattern (polar.)
Spinel	S		3.60	8	spectrum
Peridot	D	W	3.34	6-7	doubling
Jadeite	D		3.34	6.5-7	rarely trans., spectrum
Andalusite	D	S	3.18	7-7.5	pleochroic
Tourmaline	D	S	3.08	7-7.5	pleochroic
Topaz	D	D	3.56	8	cleavage
Emerald	D	S	2.71	7.5-8	inclusions, U.V.
Linde syn.	D	D	2.71	7.5-8	thin overgrowth
Chatham syn.	D	D	2.66	7.5-8	fluorescent
Quartz	D	VW	2.66	7	dull color
Chalcedony (dyed)	D (light)		2.60	6.5-7	spectrum
Glass	S(anom.)		2.3-4.5	5	molded?
Plastic	S(anom.)		<2	<3	Soft

at the temperature at which the glass is formed. The result is many inclusions that, to the casual observer, give the imitation a typical emerald "garden." It is inevitable that when glass is made with many fragments of foreign material, the number of bubbles is large, so the stone is easily detected under magnification.

A triplet consisting of two parts of beryl or two of quartz joined by an emerald-colored cement is a common substitute. Immersion discloses its nature.

Transparent green quartz is the result of heating transparent amethyst from one or two mines. This material turns green rather than to the usual citrine color resulting from the heating of amethyst. It is usually yellowish-green reminiscent of peridot. It is not an intense green color.

In addition to the gems mentioned, there are a variety of rare materials that occur in a green color and that are rarely seen as gemstones but are sometimes cut by, or for, collectors. Fluorite is often used for carvings, particularly by the Chinese; apatite is sometimes cut when found in a green color; brazilianite is greenish-yellow to yellowish-green; datolite occurs in very light green transparent crystals that furnish excellent material for faceted stones; diopside is a pyroxene with a dull green color, except when chromium is present to perform its magic in the form of a rich, almost emerald green; dioptase, the only gem material that almost always resembles the color of emerald; ekanite is a recently described metamict thorium mineral found in Ceylon in a dark green color; enstatite is usually a brownish-green; epidote is sometimes referred to as pistachio green, a distinctly yellowish-green; euclase is not infrequently a very pale bluish-green; kornerupine is usually dark brown, but it has been found in Madagascar in a bluish-green color described as sea green; kyanite may be a light bluish-green: moldavite is a natural glass that occurs in a green color more reminiscent of peridot than of emerald; sphalerite is usually a brownish-green: willemite, when transparent, is usually yellow but may be yellow-green. The identification and description of these rarely encountered gemstones is given in Chapter XV, together with the means by which they are most readily separated from the stones most strongly resembling them. However, the following table gives their refractive indices and specific gravities:

	Refractive Indices			**Specific Gravity**
Sphalerite		2.37		4.05
Gahnite		1.80		4.55
Gahnospinel		1.75		3.6 to 4.0
Epidote	1.729	1.757	1.768	3.40
Kyanite	1.716	1.724	1.731	3.62
Willemite	1.690		1.720	4.00
Diopside	1.675	1.685	1.701	3.29
Kornerupine	1.667	1.679	1.680	3.30
Dioptase	1.655		1.708	3.30
Enstatite	1.658	1.662	1.668	3.25
Euclase	1.654	1.657	1.673	3.10
Apatite	1.642		1.646	3.18
Datolite	1.626	1.654	1.670	2.95
Brazilianite	1.602	1.609	1.621	2.99
Ekanite		1.597		3.28
Moldavite		1.48		2.40
Fluorite		1.434		3.18

Chapter XX

The Identification of Transparent Yellow Gemstones and Their Substitutes

The number of transparent yellow gem species and their substitutes for the jewelry market is large. In addition, there are many more minerals cut almost exclusively for collectors that occur in various tones and intensities of yellow. A certain overlapping between this color range and the green, brown and orange categories is inevitable.

First Test. Clean the stone and examine it with the unaided eye or a low power loupe, to observe its key characteristics. Note its luster, degree of dispersion, whether doubling of opposite facet edges is visible, if there is any obvious dichroism or cleavage, and whether any of the several optical phenomena are present. Observations made initially may enable the gemologist to confirm a probable identity with a single test. If, in this preliminary examination, any of the following properties or conditions are noted, the probabilities include the following:

Double images of opposite facet edges suggest zircon, peridot, sphene or synthetic rutile.

An exceedingly low specific gravity apparent upon lifting the gem suggests amber or a plastic imitation.

Warmth to the touch (compared to the cold feel of crystalline materials) is a property of amorphous materials such as opal, and glass or plastic imitations.

Chatoyancy suggests chrysoberyl, quartz, or glass.

Strong dispersion suggests sphene, zircon, diamond, or synthetic rutile.

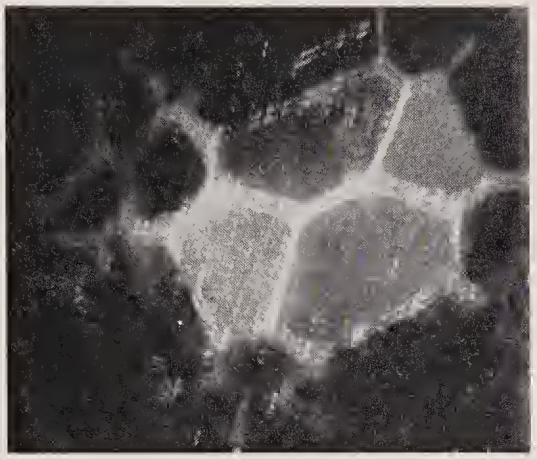

Figure 136
Doubling of opposite facet edges in a zircon.

Molded pavilion facets prove the unknown to be a glass or plastic imitation. (See Chapter XI.)
A play of color is characteristic of opal.
A luster difference between crown and pavilion or between the table and lower crown facets suggests a doublet.
A red ring around the girdle when the gem is placed table down on a white background suggests a garnet-and-glass doublet.
A visible separation plane indicates a doublet or triplet.

Second Test. After an initial inspection and classification of the unknown's color and its obvious characteristics, take a refractive index reading. If the stone has a well-polished flat facet, use the normal refractometer method. If no reading is seen and the shadow area fails to extend to the liquid line, at 1.81 (which would show that the index is over the instrument's upper limit), try the spot method.

It should be possible either to obtain a reading or to determine that the index is over the limits of the refractometer on any flat or convex polished surface, unless it is mounted in a manner that makes contact with the hemisphere impossible or unless a surface film prevents optical contact. If the refractometer findings are unsatisfactory, immersion in liquids of known index should yield an approximation of the index. (See Chapter V.) If no approximation of index seems possible, magnification, polariscope, dichroscope and spectroscope findings may serve to identify the material without a refractive index determination. In rare instances, removal of the gemstone from the mounting for better magnification or for a specific gravity test may be needed. Refractive indices are given in the following table and other properties in a second table near the end of this section.

Refractive Indices*

Syn. rutile	2.616		2.903
Diamond		2.417	
Zircon (high, med.)	1.925		1.984
Sphene	1.900	1.907	2.034
Spessartite garnet		1.81	
Corundum	1.762		1.770
Syn. corundum	1.762		1.770
Chrysoberyl	1.746	1.747	1.755
Grossularite garnet		1.745	
Syn. spinel		1.73	
Spinel		1.718	
Sinhalite	1.668	1.698	1.707
Peridot	1.654	1.672	1.690
Spodumene	1.660	1.666	1.676
Topaz	1.629	1.631	1.637
Tourmaline	1.624		1.644
Beryl	1.570		1.575
Quartz	1.544		1.553
Amber		1.54	
Copal		1.54	
Pressed Amber		1.54	
Plastics			
Polystyrene		1.59 to 1.67	
Plexiglas and lucite		1.50	
Celluloid		1.49 to 1.52	
Bakelite		1.55 to 1.67	
Glass (normal range)		1.48 to 1.70	
Glass (extreme range of gem imitation types)		1.44 to 1.77	
Opal		1.45	

* A single figure is given for isotropic, two for uniaxial, and three for biaxial materials. Variation are shown in the refractive index tables in the Appendix.

If the refractive index of the stone proves to be over 1.81, the possibilities in a yellow color include synthetic rutile, natural canary diamond. treated diamond, zircon, sphene, andradite garnet, spessartite garnet, or a garnet-and-glass doublet with a yellow color. Synthetic rutile, zircon and sphene are all characterized by a very high birefringence; however, the birefringence of synthetic rutile is more than double that of sphene, and sphene's more than double that of zircon. Synthetic rutile, which is usually a pale-yellow color, is characterized by enormous dispersion. Sphene and zircon also have rather strong dispersion but their fire is weak, compared to the excessive dispersion of synthetic rutile. Yellow zircon is usually close to 4.70 in specific gravity, but it may be as low as 4.50. On the other hand, synthetic rutile is within .02 of 4.26 and sphene has specific gravity equal to that of diamond's 3.52.

Diamond is easily distinguished from the other stones above the refractometer scale by its single refraction; typical cleavage; very fine-grained, shiny to slightly frosted texture on a lathe-turned girdle of a round brilliant; trigons or grooves on naturals (if any); and by the other characteristics described in Chapter XV. In addition, most yellow diamonds are characterized by a strong absorption line at 4155Å, deep in the violet end of the spectrum; a stone must be intensely lighted for this to be apparent. If the diamond has a natural color, only the several lines in the blue and violet, described in Chapter XIII, will be evident, although some naturally yellow diamonds show no absorption. If the stone has been subjected to cyclotron or nuclear-reactor bombardment and subsequent heat treatment, a line should be visible at 5920Å in the yellow portion of the spectrum (also at 4980 and 5040Å). The 5920Å is a very narrow line that is easily lost, unless the stone remains cool during its examination. It is often difficult to find without careful examination from several directions and under excellent lighting conditions.

Upon immersion in a liquid of high index, such as methylene iodide, a diamond remains in high relief. This is true also of synthetic rutile, whereas sphene and zircon lose most of their relief and become more difficult to see in the liquid.

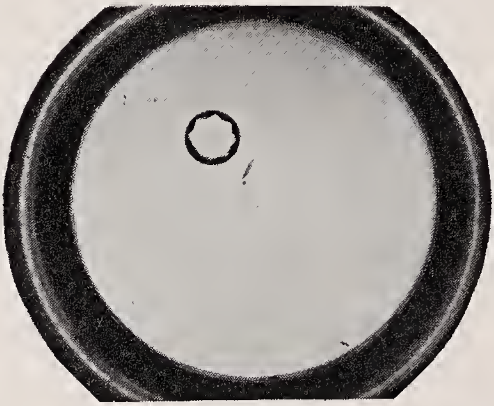

Figure 137

Diamond and synthetic spinel immersed in methylene iodide.

Spessartite garnet, which also has a characteristic absorption spectrum and is usually on the brownish side of yellow, tends almost to disappear in methylene iodide. Its refractive index is slightly above the upper limits of the refractometer.

The yellow variety of andradite garnet (sometimes called topazolite by mineralogists) is also above the limits of the refractometer in index. Spessartite tends toward a brownish-yellow and topazolite toward a greenish-yellow color. Although some andradite of a yellow-green color is known among hobbyists as topazolite, an andradite of a yellow color that would justify comparison to topaz, as the name suggests, is seldom, if ever, found in a size large enough for practical gem use. If some appears, its index above the scale (yet far below diamond, as shown by immersion), strong dispersion, single refraction, and a 3.8 specific gravity could identify it.

Garnet-and-glass doublets occasionally have a garnet top with an index above the scale, but immersion or examination under magnification quickly reveals the difference between the garnet and the glass portions.

In the next range of indices, the 1.70's, are corundum, synthetic corundum, chrysoberyl, hessonite garnet, synthetic spinel and spinel. In a yellow color, synthetic and natural sapphire are more likely to be difficult to separate by magnification than in almost any other color. Under magnification, both are sometimes free from the imperfections that would permit easy separation. In addition, the synthetic does not show visible curved striae by any method so far discovered. However, fortunately, there are means by which they may be separated beyond question. Synthetic sapphire shows no absorption lines in the spectroscope and it is not fluorescent. Natural sapphire, on the other hand, either shows lines in the spectroscope or is fluorescent, depending on its source. Yellow sapphires from Thailand and Australia usually show absorption lines in the spectroscope at 4500, 4600, and 4700Å; in those with a good deal of iron, the 4500 and 4600 lines almost merge. On the other hand, yellow stones from Ceylon contain very little iron and may show no line at the 4600 and 4700Å positions; in fact, sometimes the line at 4500 is not visible. However, such yellow sapphires fluoresce strongly in a rich, orangy-yellow color, sometimes referred to as "apricot." A yellow sapphire that has neither absorption lines in the spectroscope nor fluorescence may be assumed to be synthetic.

It is possible to deepen the yellow color of sapphires by heavy dosages of X-radiation, and apparently by other forms of subatomic-particle bombardment. X-ray-produced color fades quickly in sunlight. A yellow color apparently may be driven off at only 250 to 300°C, whether naturally developed or produced by irradiation.

The form in which yellow chrysoberyl is seen most often in the jewelry trade is the honey-colored cat's-eye; the silkiness and sharp eye rather readily distinguish it from any other yellow gemstone. On rare occasions, exceptional quartz cat's-eyes are seen with a silkiness and consequent sharpness of eye closely resembling fine chrysoberyl cat's-eye; they are easily distinguished by a spot reading or specific gravity. However, if there is any difficulty in establishing the identity of a chrysoberyl by refractometer, there are other methods. Chrysoberyl is the only important yellow stone in the 1.70 range that is biaxial. It should be rather easy to establish this fact by finding an interference figure in the polariscope, if the stone is sufficiently transparent; if not, other characteristics are useful. It has a dependable absorption pattern in the spectroscope and a distinct line at approximately 4450Å (see table of characteristic absorption spectra in Chapter XIII). In the unlikely event there is any doubt as to its identity, it should be simple enough to distinguish between corundum and synthetic corundum on the one hand and chrysoberyl on the other by a specific gravity determination or a careful refractive index reading. The constant (and high) index of corundum is at 1.77 and the alpha and beta indices of chrysoberyl are both below 1.75.

At almost the same refractive index as chrysoberyl is grossularite garnet. The hessonite variety of grossularite is usually a brownish-yellow to yellowish-brown and is characterized under magnification by a very distinctive appearance; this appearance is very well shown in Chapter VIII on inclusions. Grossularite, in contrast to the other stones above it in index in the 1.70 range, is singly refractive. The combination of its single refraction at a 1.745 refractive index and its characteristic appearance under magnification — the appearance of a saturated sugar solution with light passing through it — is sufficient to identify it beyond question.

For practical purposes pure yellow spinel is unknown, but some may regard occasional flame spinels as more yellow than orange. Yellow synthetic spinel is encountered frequently; it is separated from the natural readily on the basis of its strong, strain-patterned double refraction and approximately .01 difference in refractive index. The synthetic is usually 1.73 or just slightly lower, and spinel between 1.715 and 1.72.

In the 1.60's the relatively common gem species are peridot, spodumene, topaz and tourmaline. Peridot is rarely a true yellow, but often may be described as greenish-yellow. Its birefringence is distinctly greater than any other gemstone likely to be encountered in a yellow color in the 1.60 refractive index range, with the exception of sinhalite, a gem mineral long thought to be iron-rich peridot. Sinhalite is usually yellow or brown in color. Its refractive indices are distinctly higher than those of gem peridot (1.668 and 1.707 compared to the 1.654 and 1.690 of peridot); however, iron-rich peridot has indices higher than the figures quoted. It is rarely, if ever, encountered on the gem market; even if it were, the refractometer could be used to separate the two, for there is a key difference between the two. Peridot is characterized by the fact that the middle index, the point from which the high and low indices vary as the stone is rotated on various facets, is 1.672; this is exactly halfway between the high and low readings. This means that it is neither really positive nor negative in sign but halfway between. In contrast, sinhalite is distinctly negative in sign; the beta reading is 1.698, only .009 from the highest index. Sinhalite has a specific gravity near 3.46, so it sinks rapidly in methylene iodide, in contrast to peridot at 3.32 to 3.35, which usually sinks very slowly. The two differ materially in absorption spectra. (See the table in Chapter XIII.) Almost the only other relatively common stone with which peridot is likely to be confused in index is spodumene, with indices of 1.660 and 1.676. However, spodumene at the highest index does not approach the 1.69 of peridot, nor does its birefringence even reach half of that of peridot. In addition, peridot has a specific gravity almost equal to the 3.32 liquid, methylene iodide, whereas spodumene floats buoyantly in this liquid.

In its yellow to yellow-brown color, topaz is characterized by a slightly higher index than it shows in either a colorless or blue form; the usual indices for yellow material are 1.629 and 1.637. It is distinctly positive in sign, with the beta index about .002 above the lower figure. Tourmaline is in the same general index range, with indices of 1.624 and 1.644, but it is optically negative in sign; the 1.644 reading is the constant figure. The birefringence of .018 to .020 is at least double that of topaz (.008). It should not be necessary to resort to a specific gravity test to distinguish between topaz and tourmaline; if this is necessary, however, a test with the 3.32 liquid quickly distinguishes between the two, since tourmaline floats and topaz sinks rapidly in methylene iodide. Both yellow and pink topaz fluoresce a dull greenish under short-wave ultra-violet. Peridot, spodumene and topaz are all biaxial and tourmaline is uniaxial.

Glass is sometimes confused with stones in this range; particularly is it likely to be confused with topaz, both in refractive index and in appearance. However, it is readily distinguished from topaz by the polariscope because, of course, glass is singly refractive.

Gemstones and substitutes with refractive indices between 1.5 and 1.6 include golden beryl, citrine quartz, amber and its substitutes, several different plastics and glass.

Most golden beryl has refractive indices of approximately 1.57 to 1.575. The only gem material in this color range that may have closely comparable indices is the rare transparent form of labradorite feldspar. Labradorite is distinguished from beryl on the basis of its biaxial character. In beryl, the high 1.575 index is constant and the 1.570 is variable. In labradorite, the two readings both vary, with the intermediate, or beta, almost at the midpoint between the extremes. The birefringence is approximately .009, or about double that of beryl. Resolution of an interference figure would be conclusive.

Bakelite is unlikely to be confused with any gemstone with the exception of amber. It is the plastic that is usually used as an amber substitute. Most often it is not yellow, as is amber, but a deeper reddish-brown, although it can be made in a yellow color. Usually, its refractive index is about 1.60, considerably higher than that of amber. It sinks rapidly in a saturated salt solution, in which amber and recent resins, such as copal or kauri gum, float. Amber is readily distinguished from plastics by the odor given off by gentle heating or by bringing a hot point against the amber. Amber gives off a strongly resinous odor, whereas various plastics have different odors, but all are characterized by an acridness. Amber is rather readily distinguished from more recent resins by the fact that if it is dipped into ether and left for a few minutes amber is unaffected, whereas the recent resins soften quickly. Pressed amber, which is made by mixing bits of amber with linseed oil and forcing the whole mass through small openings, is characterized by being softened by ether in minutes, in contrast to the natural. It also has elongated bubbles and a distinct flow structure, in contrast to the spherical nature of bubbles in amber.

Citrine quartz is characterized by its 1.544 and 1.553 refractive indices and .009 birefringence. Although the color never seems as rich as the finest topaz, citrine, or topaz-quartz, is often very attractively colored. Transparent yellow labradorite has higher indices and is biaxial, so it is easily distinguished from pale citrine.

Opal of the type that has no play of color and is transparent (usually referred to as fire opal or Mexican opal) is especially low in refractive index. For fire opal, the usual refractive index is from .01 to .08, lower than the usual 1.45 figure for black or white opal. Initially, a gem tester is likely to confuse transparent opal with glass. However, it is usually distinctly lower in refractive index than the usual 1.48 low figure for glass (or even the unusual 1.44 minimum) and also much lower in specific gravity (about 2.0).

Property Table for Yellow Gem Materials in Order of Descending Indices

Name	Polar.	Pleo.	S.G.	Hard.	Additional
Syn. rutile	D	W	4.26	6-6.5	strong doubling, fire
Diamond	S (anom.)		3.52	10	naturals, cleavage, spectrum
Zircon (high)	D	W	4.70	7-7.5	doubling, spectrum
Sphene	D	W	3.52	5-5.5	doubling
Spessartite	S (anom.)		4.15	7-7.5	spectrum
Corundum	D	D	4.00	9	inclusions, spectrum
Syn. corundum	D	D	4.00	9	inclusions
Chrysoberyl	D	D	3.73	8.5	spectrum
Grossularite	S (anom.)		3.61	7	inclusions
Syn. spinel	S (anom.)		3.65	8	inclusions
Spinel	S		3.60	8	inclusions
Sinhalite	D	W	3.48	6-7	spectrum, biaxial-, S.G.
Peridot	D	W	3.34	6-7	spectrum, S.G.
Topaz	D	D	3.53	8	S.G.
Tourmaline	D	S	3.07	7-7.5	doubling
Beryl	D	D	2.70	7.5-8	uniaxial—
Quartz	D	W-D	2.66	7	interference figure
Amber	S (anom.)		1.08	2-2.5	
Pressed amber	S (anom.)		1.08	2-2.5	inclusions
Copal	S (anom.)		1.06	2	
Glass	S (anom.)		2.3 to 4.5	5	molded?
Plastics	S (anom.)		<2.0	<3	
Opal	S		2.0	5-6.5	

Gem materials occurring in a transparent yellow form that are so rare or that possess some fault precluding regular jewelry use and, therefore, are cut almost exclusively for collectors include the following: amblygonite, apatite, axinite, beryllonite, kornerupine, brazilianite, cassiterite, danburite, euclase, fluorite, labradorite, orthoclase, phenakite, scapolite, smithsonite. sphalerite, stibiotantalite and willemite. A brief table of the principal properties of these rarer stones is given below. All are described more fully in Chapter XV.

	Refractive Indices			Specific Gravity
Stibiotantalite	2.370		2.450	7.50
Sphalerite		2.370		4.00-4.10
Cassiterite	1.997		2.093	6.95
Willemite	1.690		1.720	4.00
Axinite	1.678	1.685	1.688	3.29
Kornerupine	1.667	1.679	1.680	3.30
Euclase	1.654	1.657	1.673	3.10
Phenakite	1.654		1.670	2.95
Apatite	1.642		1.646	3.18
Danburite	1.630	1.633	1.636	3.00
Smithsonite	1.621		1.849	4.30
Amblygonite	1.612	1.623	1.636	3.02
Brazilianite	1.602	1.609	1.621	2.99
Labradorite	1.559	1.563	1.568	2.70
Beryllonite	1.552	1.558	1.562	2.85
Scapolite	1.550		1.572	2.68
Orthoclase	1.518	1.524	1.526	2.56
Fluorite		1.434		3.18

Chapter XXI

The Identification of Transparent Brown and Orange Gemstones and Their Substitutes

The gemstones that occur frequently in a brown color are not numerous. They are: vivid yellow-brown zircon and spinel, diamond. topaz. citrine, brown or orange sapphire and beryl, hessonite garnet. sphene, sinhalite, andalusite and amber and its substitutes. Several of these may be orangy-brown. Only the rare padparadscha variety of sapphire, fire opal, some Brazilian beryl and perhaps spessartite of the natural stones could be regarded as possessing a true orange color. Orange synthetic sapphire is common.

First Test. Clean the stone and examine it with the unaided eye or a low power loupe, to detect any identifying characteristics. In addition, note the luster, the degree of dispersion, whether doubling of opposite facet edges is visible, if there is any obvious dichroism or cleavage, and whether any of the several optical phenomena are present. Observations made initially may enable the gemologist to confirm a probable identity with a single test. If, in this preliminary examination, any of the following properties or conditions are noted, the probabilities include the following:

A red ring around the girdle when the gem is placed face down on white paper, or *a difference in luster along the crown facets,* indicates a garnet-and-glass doublet.

High luster suggests diamond, sphene, zircon, or synthetic rutile.

Strong dispersion (fire) suggests diamond, sphene, zircon, or synthetic rutile.

Warmth to the touch (compared to the cold feel of crystalline materials) suggests amber, glass, opal, or plastics.

Double images of opposite facet edges are often visible in a large sphene, zircon, or synthetic rutile without the aid of magnification.

A visible separation plane indicates a doublet or a triplet.

An exceedingly low specific gravity is often noticeable in amber and substitutes such as bakelite and copal.

Second Test. After an initial inspection and classification of the unknown's color and its obvious characteristics, take a refractive index reading. If the stone has a well-polished flat facet, use the normal refractometer method. If no reading is seen and the shadow area fails to extend to the liquid line, at 1.81 (which would show that the index is over the instrument's upper limit), try the spot method.

It should be possible either to obtain a reading or to determine that the index is over the limits of the refractometer on any flat or convex polished surface, unless it is mounted in a manner that makes contact with the hemisphere impossible or unless a surface film prevents optical contact. If no refractometer is available or the mounting prevents its use, immersion in liquids of known index should yield an approximation of the index. (See Chapter V.) If no approximation of index seems possible, magnification, polariscope, dichroscope and spectroscope findings should serve to identify the material without a refractive index determination. In rare instances, removal of the gemstone from the mounting for better magnification or for a specific gravity test may be needed. Refractive indices are given in the following table and other properties in a second table near the end of this chapter.

The brown or orange gemstones with indices above the refractometer's upper limit that are likely to be encountered by a jeweler include synthetic rutile, diamond, high property zircon, sphene and spessartite garnet. Garnet-and-glass doublets resembling topaz may also be over the scale in refractive index on the garnet crown.

Dark orangy-brown synthetic rutile, although not common, is second only to the pale yellow in point of use as a gem material.

Refractive Indices*

Syn. rutile	2.616		2.903
Diamond		2.417	
Zircon (high)	1.925		1.984
Sphene	1.900	1.907	2.034
Spessartite garnet		1.810	
Corundum	1.762		1.770
Syn. corundum	1.762		1.770
Chrysoberyl	1.746	1.747	1.755
Grossularite garnet		1.745	
Syn. spinel		1.730	
Spinel		1.718	
Sinhalite	1.668	1.698	1.707
Peridot	1.654	1.672	1.690
Topaz	1.629	1.631	1.637
Andalusite	1.634	1.639	1.643
Tourmaline	1.624		1.644
Beryl	1.577		1.583
Quartz	1.544		1.553
Amber		1.54	
Pressed amber		1.54	
Copal		1.54	
Orthoclase	1.518	1.524	1.526
Plastics			
Polystyrene		1.59 to 1.67	
Bakelite		1.55 to 1.67	
Plexiglas and lucite		1.50	
Celluloid		1.49 to 1.52	
Glass (normal range)		1.48 to 1.70	
Glass (extreme range of gem imitation types)		1.44 to 1.77	
Opal		1.45	

* A single figure is given for isotropic, two for uniaxial, and three for biaxial materials. Variations are shown in the refractive index tables in the Appendix.

Its brilliancy and richness of color make a very attractive gemstone. It is easily distinguished from diamond of comparable color by its enormous birefringence, which gives it a fuzzy appearance. Even through the table at a slight angle, the culet appears doubled with a significant separation between the two images. In this deep color, absorption of wave lengths at both ends of the visible spectrum reduces the apparent dispersion so much that synthetic rutile may be confused with zircon or spessartite. However, the high luster and the enormous birefringence identify synthetic rutile. If necessary, the 4.26 specific gravity distinguishes it from zircon.

Zircon may be a dull brown or the vivid orangy-brown of the type sometimes called flame zircon. Fairly strong doubling is sure to be seen under magnification if the gem is viewed in several directions, but the two images are not separated to a degree approaching that of either sphene or synthetic rutile. Zircon often shows pits along facet edges, especially the heat-treated bright red to orange and brown types. Angular inclusions and a specific gravity near 4.7 distinguish it from synthetic rutile. Zircon in a brown to orange color is likely to show the typical many-lined absorption spectrum for which the Burma and Ceylon zircons are famous; this is the spectrum attributable to uranium. (See Chapter XIII.) However, failure to see a spectrum of this type should not be interpreted as proof that the stone is not zircon, since many brown or vivid red-orange zircons fail to show it. Usually, however, zircon in a brown or red-brown color is characterized at least by a 6535Å line, usually accompanied by a 6590 line. Additional lines may or may not be present.

Sphene has a birefringence that is approximately double that of zircon and distinctly greater fire. It is easily distinguished from zircon by its low specific gravity (3.52) for such a high index. In addition, it is biaxial, in contrast to both synthetic rutile and zircon. A biaxial interference figure may be located in the polariscope, using the technique explained in Chapter VI.

Brown diamond, the so-called "coffee" or other similar colors, may either be of natural color or be colored by irradiation in a cyclotron or nuclear reactor, followed by heat treatment. Diamond, of course, is characterized by its single refraction, high luster, sharp facet edges, and its characteristic lathe-turned surface on unpolished girdles, which is unlike that of any other gemstone. In addition, cleavages are frequently seen at or near the girdle, a condition not to be seen in any of the other important stones above the refractometer in index. The cause of color is best ascertained with a spectroscope, where the presence of a 5920 line in the yellow portion is proof of artificial origin of color. (See Chapters XIII and XV.)

Spessartite garnet, like diamond, is singly refractive, but it is distinctly lower in luster. It is readily distinguished from diamond by immersion in a high refractive index liquid, such as methylene iodide (1.74), in which it almost disappears. The spectroscope provides a positive means of separating the two. This same immersion test serves to distinguish spessartite from a garnet-and-glass doublet with an almandite top. Usually, it has a refractive index near the upper limit of the refractometer, rather than above it.

In the 1.70's range, there are corundum, synthetic corundum, the rarely seen brown chrysoberyl, the hessonite variety of grossularite garnet. and spinel. Truly orange or brown synthetic spinel is not available. commercially, at present. Distinguishing between natural and synthetic padparadscha (orange sapphire) is one of the separations most likely to give difficulty. Synthetic padparadscha is quite common. so it is inevitable that occasionally one will be seen that has no inclusions and in this color curved striae may be almost impossible to resolve. Better success in resolving striae may be gained if the immersion liquid is not methylene iodide but a liquid with a much lower index. Bromoform, at 1.59, is about right in index but the fumes are so unpleasant that some other liquid is suggested. The spectrum and fluorescence could be identical for synthetic and natural. Thus, it is sometimes particularly difficult to distinguish the synthetic from the natural. Natural orange sapphire is very rare. but when it does occur the orange color frequently is accounted for by a combination of iron and chromium as coloring agents. If the iron appears in the spectrum in the form of lines from 4500 to 4700Å, one can be satisfied that the stone is natural. However. if only chromium lines are noted and it is flawless, the probability is that it is synthetic. The synthetic identification may be confirmed by using the method first described by Dr. Plato, a German mineralogist. The unknown stone is examined in the polariscope to find the optic axis direction. Examination in this direction under about 20 to 30X, with the unknown between crossed Polaroids, discloses two or three sets of parallel lines resembling those caused by repeated twinning at 60° to one another.

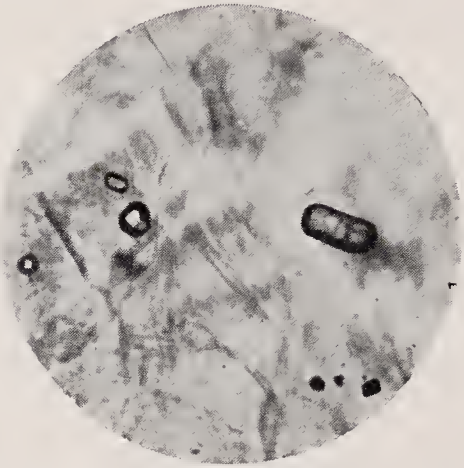

Figure 138
Diopside crystals and roiled effect in hessonite.

(See Chapter X for precise directions.) This condition is seen in the synthetic, but not in natural corundum.

Chrysoberyl in a brown color is not common, but it is encountered on occasion. Its positive optic sign and refractive index in the 1.75 range should identify it. However, if necessary, securing an optic interference figure will distinguish it easily from corundum. In addition, chrysoberyl has a distinctly lower specific gravity (3.73) compared to that of corundum (4.0). Brown chrysoberyl has an absorption spectrum made distinctive by the presence of a strong band from about 4400Å to 4520Å and a narrower band near 4290Å. The absorption in brown stones is so strong that the spectrum is almost cut off at 4500Å. (See Chapter XIII.)

At about the same index, 1.745, is hessonite garnet. It is characterized by the inclusions described and pictured in Chapter VIII. The odd granular effect that is often seen in grossularite is comparable to the roiled appearance of a saturated solution of sugar and water; it has been referred to as the appearance of heat waves over hot pavement. Diopside prisms of very low relief are found throughout the material. Thus, the distinctive appearance of grossularite under magnification and the double refraction of chrysoberyl should serve to distinguish the two readily. Hessonite is an orangy-brown and chrysoberyl a purer brown.

Synthetic spinel is all but unknown in an orange to brown color, but natural spinel in a vivid red-orange type is common. The latter has an index of about 1.715 to 1.720; i.e., a single refractive index somewhere between these figures. Colorless synthetic spinel is used often in the manufacture of triplets composed of two parts of the synthetic and a color-imparting cement. Such triplets are easily detected by immersion.

In the 1.60 to 1.70 index range there are several possibilities. Topaz and tourmaline head the list, but sinhalite (long thought to be brown peridot), the very rarely encountered brown peridot, andalusite, and the usual substitutes are all possibilities. Orangy-brown colored topaz has indices of 1.629 and 1.637, or very close to these values. It takes an excellent polish, so it seems often to have a higher luster than its index range suggests; also, it has a slippery feel. Tourmaline, with an .02 birefringence, has refractive indices (1.624 and 1.644) both above and below topaz. Since tourmaline is uniaxial negative, the constant reading is the higher figure. Occasionally, it may be necessary to obtain an interference figure or to use heavy liquids to separate the two. Topaz is biaxial and sinks in 3.32. Tourmaline is uniaxial and floats in 3.32.

Sinhalite may be distinguished from brown peridot on the refractometer, since it has a strongly negative sign (beta is much closer to the high index), and peridot has its intermediate index almost exactly halfway between the high and the low indices. (See Chapter VI.) The indices of sinhalite are higher than peridot, even when the latter is brown. Although the series of which peridot is a member has brown members with higher properties, they are not transparent. There are distinct differences in absorption spectra. (See table in Chapter XIII.)

Andalusite is easily distinguished from topaz by specific gravity and from tourmaline by the latter's greater birefringence on the refractometer. Brown tourmaline is very strongly dichroic, since one of the vibration directions is almost totally absorbed.

The single reading for glass may be anywhere in the 1.60's, but it often resembles topaz in properties; therefore, 1.62 or 1.63 is a common reading for topaz-colored glass. It is easily distinguished by the polariscope, or under magnification. In the polariscope, of course, glass is singly refractive, and under magnification, bubbles or swirl lines are often seen. On the other hand glass is often flawless, but it is not uncommon for either topaz or tourmaline to be flawless also. Molded facets often reveal the identity of glass to the unaided eye. Topaz may show incipient cleavage cracks under magnification. Among brown gems and substitutes in this refractive index range, plastic is a possibility, but it is easily eliminated by heft, warmth to the touch and its very low hardness. Usually, it is possible to scratch or dent plastic with a fingernail.

In the 1.50's there are a number of possibilities, including beryl, plastics of various types and indices, quartz, amber and pressed amber, plus recent resins such as copal or kauri gum. Glass, too, is a possibility in this refractive index range. Beryl may be near 1.58 in index, but 1.57 to 1.575 is a more common pair of readings for brown or orangy beryl. Quartz is always near 1.544 to 1.553, with the constant .009 birefringence. In a yellow-brown color, the pleochroism of citrine is usually very weak. Sometimes a very dark brown variety of quartz known as morion or smoky quartz, is encountered with distinct pleochroism. The yellow to yellow-brown or reddish-brown variety of quartz is usually the result of heat treating either smoky quartz or amethyst.

There are two or three problems connected with the identification of amber, because it is sometimes tampered with and substitutes may resemble it closely. Pressed amber, formed by consolidating amber chips by heat and pressure (forcing softened material through a mesh to form a homogenous mass), could be considered reconstructed amber. It is distinguished from block amber under magnification, because the air bubbles seen in amber are spherical in contrast to the numerous elongated bubbles in pressed amber. Pressed amber shows flow lines resembling the swirl marks in glass. Copal, or kauri gum, recent resins, are softened quickly by drops of ether. Ether evaporates so quickly that several drops may be needed to be sure. If practical, a corner of the piece may be dipped into ether. One reason for tampering with amber is to hide effects of ageing and damage caused by careless use of cleaning solutions.

Identification of Transparent Brown, Orange Gemstones

Amber, copal and pressed amber are all distinguished from plastic substitutes by the reaction to a hot point, either an electrically heated needle or even a needle heated by the flame of a match. The difference lies in the resinous odor of amber, copal or pressed amber, compared to the acrid odors of plastics. Obviously, heat or a hot point must be used with great caution to avoid damage. A simpler method for distinguishing these materials from plastics is to use a saturated salt solution. Common salt in a saturated solution in water has a density of about 1.13. In this solution, bakelite, the most common amber substitute, sinks and the natural resins float. Of the plastics, only polystyrene floats, and its refractive index of 1.63 distinguishes it from amber (1.54).

PROPERTY TABLES FOR BROWN AND ORANGE MATERIALS IN ORDER OF DESCENDING INDICES

Name	Polar.	Pleo.	S.G.	Hard.	Additional
Syn. rutile	D	W	4.26	6-6.5	doubling
Diamond	S(anom.)		3.52	10	girdle, cleavage
Zircon (high)	D	W	4.70	7-7.5	doubling
Sphene	D	W	3.52	5-5.5	doubling
Spessartite	S(anom.)		4.15	7-7.5	spectrum
Corundum	D	S	4.00	9	inclusions, spectrum
Syn. corundum	D	S	4.00	9	inclusions, spectrum
Chrysoberyl	D	S	3.73	8.5	spectrum
Grossularite	S(anom.)		3.61	7	inclusions
Spinel	S		3.60	8	inclusions
Sinhalite	D	S	3.45	6-7	biaxial-
Peridot	D	W	3.34	6-7	birefringence
Andalusite	D	D	3.18	7-7.5	pleochroic
Topaz	D	D	3.53	8	cleavage
Tourmaline	D	S	3.07	7-7.5	doubling
Beryl	D	D	2.70	7.5-8	uniaxial-
Quartz	D	W-D	2.66	7	interference figure
Amber	S(anom.)		1.08	2-2.5	
Pressed amber	S(anom.)		1.08	2-2.5	
Copal	S(anom.)		1.06	2	
Glass	S(anom.)		2.3 to 4.5	5	molded?
Opal	S		2.00	5-6.5	
Plastics	S(anom.)		<2	<3	

One other possibility in the brown and orange category is fire opal (the type without play of color), which may have an index well below 1.45. The usual index for transparent opal is near 1.45, but indices as low as 1.37 have been encountered. Usually, it is at or below the minimum figure for glass in refractive index and the specific gravity is always lower than that of glass.

There are a number of brown and orange transparent materials that are cut for collectors but almost never for jewelry purposes. Many could be named, but the line is drawn at those actually tested at the GIA Laboratories and those with a durability that makes their use for ornamental purposes feasible. Their refractive indices and specific gravities are listed below. They are described more fully in Chapter XV.

	Refractive Indices			Specific Gravity
Stibiotantalite	2.370		2.450	7.50
Anatase	2.493		2.554	3.90
Sphalerite		2.370		4.05
Cassiterite	1.997		2.093	6.95
Scheelite	1.918		1.934	6.12
Staurolite	1.736	1.741	1.746	3.75
Idocrase	1.713		1.718	3.40
Willemite	1.690		1.720	4.00
Axinite	1.678	1.685	1.688	3.29
Diopside	1.675	1.685	1.701	3.29
Kornerupine	1.667	1.679	1.680	3.30
Enstatite	1.658	1.662	1.668	3.25
Apatite	1.642		1.646	3.18
Labradorite	1.559	1.563	1.568	2.70
Obsidian		1.50		2.45
Fluorite		1.434		3.18

Chapter XXII

The Identification of Transparent Pink and Red Gemstones and Their Substitutes

There are so many gemstones that occur in various tones of red, from dark red to very light red, that particular care is needed in their identification. Some, such as corundum and synthetic corundum, occur from light pink to very intense medium and even dark red, and others occur only in one or two tones. Diamond, synthetic spinel, spodumene, topaz, beryl and quartz occur almost exclusively in light or very light tones of red.

First Test. Clean the stone and examine it with the unaided eye or a low power loupe, to detect any identifying characteristics. In addition, note its luster, degree of dispersion, whether doubling of opposite facet edges is visible, if there is any obvious dichroism or cleavage, and whether any of the several optical phenomena are present. Observations made initially may enable the gemologist to confirm a probable identity with a single test or two. If, in this preliminary examination, any of the following properties or conditions are noted, the probabilities include the following:

Distinct color change from daylight to artificial light may indicate chrysoberyl (alexandrite), synthetic alexandrite-like corundum or spinel, or andalusite.

Adamantine luster suggests diamond or synthetic rutile.

Strong dispersion suggests diamond, zircon, or synthetic rutile.

Dichroism obvious to the unaided eye suggests kunzite, andalusite or alexandrite.

Warmth to the touch (compared to the cold feel of crystalline materials) is a property of amorphous materials such as opal and glass and plastic imitations.

An exceedingly low specific gravity is often noticeable in plastic imitations, when a large stone is hefted.

Double images of opposite facet edges are often visible in synthetic rutile or a large zircon, without aid of magnification.

A luster or color difference between portions of the stone or a visible joining plane suggests a doublet or triplet.

A coated back on a star stone proves a star foil back.

Molded back facets prove the unknown to be a glass or plastic imitation. (See Chapter XI.)

Second Test. After an initial inspection and classification of the unknown's color and its obvious characteristics, take a refractive index reading. If the stone has a well-polished flat facet, use the normal refractometer method. If no reading is seen and the shadow area fails to extend to the liquid line, at 1.81 (which would show that the index is over the instrument's upper limit), try the spot method.

It should be possible either to obtain a reading or to determine that the index is over the limits of the refractometer on any flat or convex polished surface, unless it is mounted in a manner that makes contact with the hemisphere impossible or unless a surface film prevents optical contact. If refractometer findings are unsatisfactory, immersion in liquids of known index should yield an approximation of the index. (See Chapter V.) If no approximation of index seems possible, magnification, polariscope, dichroscope and spectroscope findings may serve to identify the material without a refractive index determination. In rare instances, removal of the gemstone from the mounting for better magnification or for a specific gravity test may be needed. Refractive indices are given in the following table and other properties in a second table near the end of this section.

There are several gemstones above the upper limit of the refractometer in this color range, as well as in most other colors.

Identification of Transparent Pink, Red Gemstones

These include an unusual color of synthetic rutile, diamond, high and medium zircon, almandite garnet and garnet-and-glass doublets.

Synthetic rutile is characterized by an enormous birefringence of .287 and unparalleled dispersion. Diamond, almost unknown in a bright red color, is unusual but sometimes available in pink. Garnet-red stones are less rare. Treated pink diamonds seen to date have been under one-fourth carat. Natural pinks are usually

REFRACTIVE INDICES*

Synthetic rutile	2.616		2.903
Diamond		2.417	
Zircon (high, med.)	1.925		1.984
Almandite garnet		1.80	
Spessartite garnet		1.80	
Corundum	1.762		1.770
Synthetic corundum	1.762		1.770
Rhodolite garnet		1.76	
Chrysoberyl	1.746	1.747	1.755
Pyrope garnet		1.746	
Synthetic spinel		1.73	
Spinel		1.718	
Spodumene	1.660	1.666	1.676
Andalusite	1.634	1.639	1.643
Topaz	1.629	1.631	1.637
Tourmaline	1.624		1.644
Beryl	1.585		1.594
Quartz	1.544		1.553
Amber		1.54	
Plastics			
Polystyrene		1.59 to 1.67	
Bakelite		1.55 to 1.67	
Plexiglas and lucite		1.50	
Celluloid		1.49 to 1.52	
Glass (normal range)		1.48 to 1.70	
Glass (extreme range of gem imitation types)		1.44 to 1.77	
Opal		1.45	

*A single figure is given for isotropic, two for uniaxial, and three for biaxial materials. Variations are shown in the refractive index tables in the Appendix.

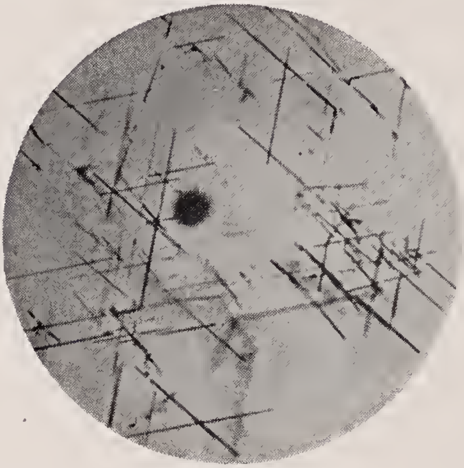

Photo by E. Gubelin

Figure 139

Needlelike inclusions in almandite. Only two sets are in the same plane.

very pale in color, whereas the treated pink is usually a strongly colored brownish-pink. The brownish-pink treated stones show the 5920Å absorption line in the yellow portion of the spectrum, in contrast to natural pink or garnet-red diamonds. Failure to show such a line, plus the pale pink color, characterizes the natural stone.

Zircon in a reddish color is usually that with properties in the medium range, but it may be the high property type. Almost all zircons are characterized by the 6535 line in the red portion of the spectrum, with another accompanying line at 6590Å. However, in a red color zircon quite frequently is without any visible line in the spectrum. Occasionally, zircon in this color resembles almandite garnet, but it is easily distinguished from garnet by its high birefringence seen under magnification. Although it is unlikely to be confused with synthetic rutile, zircon could be distinguished from it when necessary by the great difference in birefringence and fire. Furthermore, the specific gravity of zircon, even in the medium property range, is usually 4.50 or above, in contrast to the 4.26 of synthetic rutile. Almandite garnet is encountered with refractive indices all the way from corundum, at about 1.77, up to slightly above the scale. When the index is below 1.78, it is easily confused with the dark red grade often called Siam ruby. Although

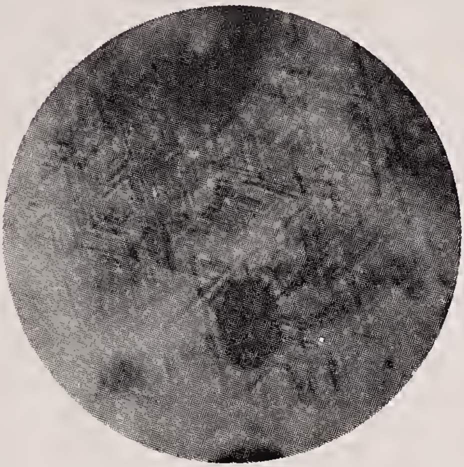

Figure 140

Three sets of needlelike inclusions in the same plane in ruby.

garnet is singly refractive and ruby doubly refractive, the polariscope reaction is often unsatisfactory in the case of single refractive almandite garnet because of its frequently strong anomalous double refraction. The method for using the polariscope to distinguish between singly refractive stones showing anomalous double refraction and truly doubly refractive stones is explained in Chapter VI. In addition, ruby is strongly dichroic, whereas garnet shows no dichroism whatever. More important, there are also distinct differences in the absorption spectra of the two stones, as shown in the tables accompanying Chapter XIII. Furthermore, the doubling in ruby should be visible under magnification, whereas none is evident in singly refractive almandite. Under ultra-violet light the garnet is inert, whereas the ruby almost always fluoresces, especially noted in a darkened room.

All that has been said with respect to almandite may be said in regard to rhodolite garnet, with the exception of the refractive index range. Rhodolite is actually a mixture of pyrope and almandite that is usually lighter in color than either in a violetish-red or a light brownish-red color. In its violetish-red form, rhodolite bears a very close resemblance to ruby. Like almandite, rhodolite may be separated from ruby by magnification, which should disclose doubling in corundum but not in garnet; by the dichroism

Figure 141

Repeated twinning laminations in corundum.

of corundum; by the difference in the absorption spectra of the two stones or by the difference in their ultra-violet fluorescence.

The methods by which natural and synthetic ruby may be identified are explained in detail in Chapter X. A short discussion seems necessary at this point, however.

Natural ruby is rarely without inclusions that are obvious under 10X. Although freedom from obvious inclusions should make the tester suspicious, it is only an indication. A very fine ruby may be flawless or nearly flawless. The major basis for separation is provided by magnification, to determine whether inclusions are spherical or elongated gas bubbles and curved striae, characteristics of a synthetic, or the angular inclusions and straight banding associated with a natural ruby. A hexagonal pattern of inclusions or banding in a natural stone is oriented so that the hexagonal arrangement is seen when viewed parallel to the optic axis, the direction of no dichroism (in a natural ruby, this is usually through the table). In a synthetic, curved striae are seen in a direction of strong dichroism, also usually through the table. Parallel glide planes or parting planes are very rarely seen in synthetic corundum. They could be confused with repeated twinning lines in the natural.

Synthetic ruby that has been heated to a high temperature and then quenched in a liquid has many fractures and may have what appears to be dendritic inclusions in the breaks. Bubbles and curved striae should be detectable however.

There should be no difficulty in distinguishing alexandrite chrysoberyl from corundum or garnet, because of the fact that it changes from garnet red under artificial incandescent light to green in daylight. In addition, it is strongly trichroic. The usual imitation of alexandrite, synthetic sapphire, changes from an amethystine color in artificial light to a grayish-blue in daylight. Natural sapphire with a color change usually changes from violetish color to blue. Synthetic spinel with an alexandrite-like color change has been encountered only a few times, but it is by far the best imitation of alexandrite in appearance. The colors are very similar to those of alexandrite (chrysoberyl). Since it is singly refractive, synthetic spinel shows no pleochroism. Its approximately 1.728 refractive index is sufficiently separated from that of chrysoberyl to permit ready identification by a careful tester. Their absorption spectra differ also. (See Chapter XIII.) The usual reading for chrysoberyl is less likely to be confused with that of corundum than the figures in refractive index tables might suggest. Because chrysoberyl is positive in sign and the beta index is only .001 higher than the 1.746 of the alpha, the usual white light reading is seen on the low side of 1.75. Since ruby is uniaxial and negative in sign, the high reading at 1.77 is constant and always in evidence; therefore, the two stones are not likely to be confused on the refractometer.

Pyrope garnet is usually between 1.74 and 1.75 in refractive index, but it may be as low as 1.73 and very rarely down to 1.725. Red spinel is almost always just below 1.72, but figures as high as 1.744 have been reported. Distinguishing between chromium pyrope and natural red spinel is accomplished by a spectroscope. The difference between the two is evident by a comparison of the two spectra illustrated in the table in Chapter XIII. In addition, the usual inclusions in the two materials differ considerably. Spinel is characterized by the presence of octahedra. They may be large or so small that they are very difficult to resolve well enough to make out their shape. Sometimes individual crystals are scattered throughout, but more often they are grouped in irregular sheets that resemble the "fingerprints" in corundum. Pyrope usually has needlelike inclusions, plus crystals or rounded grains of low relief.

Synthetic spinel in this color category may have several different forms. For years, it was not made in a rich red color by the Verneuil process. Most of the synthetic spinel is a very light red that resembles pink topaz or kunzite, rather than ruby. However, red synthetic spinel has been produced by the Verneuil process recently, but only in sizes yielding cut stones of well under one carat. There are some absorption spectra shown for it in the table in Chapter XIII. Another type of synthetic spinel that is very rare is that described earlier as an excellent substitute for alexandrite. Spinel and synthetic spinel are easily distinguished by the difference in refractive index and the fact that the synthetic shows the strong so-called "cross-hatched" anomalous double refraction under 5X to 10X in the polariscope. Hydrothermal synthetic spinel crystals have been described on one or two occasions, but apparently have never reached commercial gem markets.

Garnet-and-glass doublets have long been used as imitation rubies. They are made in colors very similar to those of natural rubies. In a red color, they are slightly harder to detect than in other colors, for the "red-ring" test described in Chapter XI is not useful in this separation. However, the luster difference between garnet and glass, usually visible on the crown, is sufficient to give them away. Magnification also discloses the difference in transparency between parts. Glass in a red color is rarely made with an index over 1.70. When the index is this high, the lead content makes the hardness too low for the imitation to be practical as a gem imitation, but high index glass imitations are seen more often in a red color than in other colors. It may be detected by its single refraction, high specific gravity, warmth to the touch, plus gas bubble inclusions and swirl lines seen under magnification.

In the 1.60's range, there are a number of gemstones in a red or light red color. Among these is spodumene, the most important variety of which is kunzite. Kunzite has a dichroism so strong that it is usually visible to the unaided eye when examining the stone in different directions. The two colors are (1) almost colorless and (2) a rich purplish-red to violet. The refractive indices of kunzite, 1.660 to 1.676, are distinctly different from those of any of the other usually encountered gems in the pink and red color categories. Spodumene is usually nearly free from flaws (except for long silk-like solution cavities), but the strong two-directional cleavage is sometimes evident in cut stones.

A relatively uncommon gemstone that is being cut more frequently today than in the past is andalusite. In its gem variety, it is usually very strongly dichroic with a brownish-red color in one direction and a green in another; however, weakly dichroic pink stones are known. The bicolored nature of this stone, with both green and reddish-brown reflections evident to the unaided eye, gives andalusite a superficial resemblance to alexandrite. However, the color does not change from one light source to another. Its birefringence of approximately .009 is distinctly below that of spodumene, but close to that of another stone in the pink to red category, topaz, which in this color has indices of 1.629 and 1.637.

Topaz has a positive sign, with the intermediate index at about 1.631, only approximately .002 from the low reading. There is no likelihood of confusion with andalusite, because of the obviousness of the green dichroic color of that gem. Topaz is rarely dark red in color, but is usually a light violetish-red to reddish-violet. The chromium that causes the pink color is evident in the distinctive absorption spectrum of heat-treated pink topaz. The strong basal cleavage in topaz is also sometimes evident in a cut stone. Flat liquid-and-gas inclusions are not uncommon, and often there are two immiscible liquids within such cavities. This is very unusual in any other gemstones. Pink topaz fluoresces a dull green under short-wave ultra-violet.

Tourmaline varies from pink to deep red. Usually, it is much more strongly colored than either spodumene or topaz and is very strongly dichroic. Red tourmaline has a distinctive absorption spectrum, shown in the tables in Chapter XIII, and it is readily distinguished from other gemstones in its refractive index range by its very strong birefringence, .020. This is considerably greater than topaz or andalusite and somewhat greater than spodumene. It is easily distinguished from spodumene by the fact that it has distinctly lower refractive indices and is negative in sign, so that the constant index is the high one, in contrast to the wide variability of the high index in spodumene.

The substitutes that may resemble the gemstones with indices in the 1.60's are synthetic spinel (1.73), synthetic corundum (1.76-1.77) glass and plastic. Glass, plastic and synthetic spinel are easily distinguished from spodumene, topaz and tourmaline by their singly refractive character; and both synthetic spinel and synthetic corundum, by the difference in refractive indices from the gemstones in the 1.60's.

The morganite variety of beryl is another gemstone that may resemble topaz and kunzite, in that it occurs in a light violetish-red color. Morganite is usually higher in both refractive index and birefringence than most of the other beryl varieties. Its usual indices are 1.585 and 1.594, and its birefringence is approximately .009. Beryl occurs naturally in a light pink color, but much of the morganite on the market is the result of heat treatment of a yellow to reddish-yellow colored beryl from a district in Brazil. Since beryl is negative in sign and uniaxial, the 1.594 index is constant and the lower index variable. As it is the only doubly refractive pink or red gemstone near 1.58 or 1.59, there should be little difficulty in identifying this variety of beryl.

Rose quartz is very rarely transparent, but on occasion it is sufficiently transparent to be faceted. More often, it is seen in cabochon form and in carvings. It is usually semitransparent to translucent, rather than transparent. It is enough lower in refractive index (approximately .04) below pink beryl that it is easily distinguished from morganite. Rose quartz may be composed of small enough grains so that it remains light rather than changing from light to dark in the polariscope, but this is rare. It sinks in a 2.62 specific gravity liquid, in contrast to chalcedony, which floats. Citrine quartz of the heat-treated type may be almost garnet-red in color, so it is still another possibility in this broad color category.

Glass with an index comparable to beryl, quartz or chalcedony is often encountered, but it is easily distinguished from these other gemstones by its single refraction. Glass may be molded, rather than polished. Concave facets disclose its molded origin. The same may be said of plastics, which are usually distinguished very readily simply by their light "heft," caused by their very low specific gravity. Bakelite may have an index anywhere from approximately 1.55 to 1.67, with the usual figure in the 1.60's. Again, its single refraetion and light heft make it very readily identifiable.

Below the 1.44 lower limit likely to be encountered in glass is another natural gemstone, a transparent orangy-red opal, at approximately 1.43 (even down to 1.37). The specific gravity of fire opal is about 2.00, a figure below glass and above plastic.

PROPERTY TABLES FOR RED AND PINK GEM MATERIALS IN ORDER OF DESCENDING INDICES

Name	Polar.	Pleo.	S.G.	Hard.	Additional
Syn. rutile	D	W	4.26	6-6.5	doubling
Diamond	S (anom.)		3.52	10	girdle, cleavage
Zircon (high)	D	W	4.70	7.5	doubling
Zircon (med.)	D	W	4.40	7.5	doubling
Almandite	S (anom.)		4.05	7.5	spectrum
Corundum	D	S	4.00	9	inclusions
Syn. corundum	D	S	4.00	9	inclusions
Rhodolite	S (anom.)		3.84	7-7.5	spectrum
Chrysoberyl	D	S	3.73	8.5	color change
Pyrope	S (anom.)		3.78	7-7.5	spectrum
Syn. spinel	S (anom.)		3.64	8	strain pattern
Spinel	S		3.60	8	spectrum
Spodumene	D	S	3.18	6-7	fluorescent, pleochroic
Andalusite	D	S	3.18	7-7.5	pleochroic
Topaz	D	S	3.53	8	
Tourmaline	D	S	3.04	7-7.5	pleochroic
Beryl	D	D	2.82	7.5-8	uniaxial-
Quartz	D	VW	2.66	7	rarely transparent
Amber	S (anom.)		1.08	2-2.5	rare
Plastics	S (anom.)		<2.00	<3	
Glass	S		2.3-4.5	5	molded?
Opal	S		2.00	5-6.5	

There are a number of red or pink transparent materials cut for collectors but that almost never are cut for jewelry purposes. Many could be named, but the line is drawn at those actually tested at the GIA Laboratories and those with a durability that makes their use for ornamental purposes feasible. These include the minerals listed in the following table. They are described more fully in Chapter XV.

	Refractive Indices			Specific Gravity
Rutile	2.616		2.903	4.26
Sphalerite		2.37		4.05
Zincite	2.013		2.029	5.70
Cassiterite	1.996		2.090	6.95
Painite	1.787		1.816	4.01
Epidote	1.740	1.760	1.790	3.40
Willemite	1.690		1.720	4.00
Phenakite	1.654		1.670	2.95
Danburite	1.630	1.633	1.636	3.00
Apatite	1.642		1.646	3.18
Rhodochrosite	1.597		1.817	3.70
Scapolite	1.550		1.572	2.68
Apophyllite	1.535		1.537	2.40
Pollucite		1.520		2.92
Fluorite		1.434		3.18

Chapter XXIII

The Identification of Transparent Colorless Gemstones and Their Substitutes

The most important colorless or nearly colorless transparent gemstone is diamond. However, there are many other colorless natural gemstones and substitutes cut for jewelry use. Most of them have been mistaken for diamond or used to imitate diamond at one time or another. Certainly, synthetic rutile, strontium titanate (or Fabulite), zircon, both synthetic and natural colorless sapphire, synthetic spinel, topaz, beryl, rock crystal quartz, glass, glass foil backs, diamond doublets, doublets composed of synthetic rutile and synthetic sapphire, doublets of Fabulite and synthetic sapphire, and garnet-and-glass doublets all have been confused with diamond or used to imitate diamond. The variety of orthoclase known as precious moonstone, and its substitutes (synthetic spinel, white chalcedony, milky quartz, glass and plastic), also are considered in this category because moonstone itself is nearly transparent. Although chalcedony is semitransparent at best, it is considered here as well as under the nontransparent white classification. The other stones considered under the transparent colorless category include rare or seldom cut varieties of some of the other gemstones, such as spinel, spodumene and beryl. Finally, a list of rare species of interest to collectors is given at the end of the section.

First Test. Clean the stone and examine it with the unaided eye or a low power loupe to detect any identifying characteristics. Observe particularly its luster, strength of its dispersion, and whether doubling is noticeable when looking toward opposite facet edges. As a last step, look for any optical phenomenon that may be present. Among colorless stones, play of color, a weak star or cat's-eye, or the blue sheen of adularescence are about the only likely possible phenomena. In this preliminary examination, observation of any of the following properties may facilitate identifications:

Strong dispersion suggests diamond, zircon, strontium titanate, or synthetic rutile.

Doubling of opposite facet edges suggests zircon, tourmaline, or synthetic rutile.

Play of color suggests opal.

Blue sheen in reflected light suggests precious moonstone (orthoclase feldspar).

Adamantine luster suggests diamond, zircon, synthetic rutile, or strontium titanate.

A luster difference or a plane of separation between crown and pavilion or between the upper and lower portions of the crown suggests a doublet.

A foilback, if present, should be apparent by inspection.

Second Test. After an initial inspection and classification of the unknown's obvious characteristics, take a refractive index reading. If the stone has a well-polished flat facet, use the normal refractometer method. If no reading is seen and the shadow area fails to extend to the liquid line, at 1.81 (which would show that the index is over the instrument's upper limit), try the spot method.

It should be possible either to obtain a reading or to determine that the index is over the limits of the refractometer on any flat or convex polished surface, unless it is mounted in a manner that makes contact with the hemisphere impossible or unless a surface film prevents optical contact. If the refractometer findings are unsatisfactory, immersion in liquids of known index should yield an approximation of the index. (See Chapter V.) If no approximation of index seems possible, magnification, polariscope, dichroscope and spectroscope findings should serve to identify the material without a refractive index determination. In rare instances, removal of the gemstone from the mounting for better magnification or for a specific gravity test may be needed. Refractive indices are given in the following table and other properties in a second table near the end of this chapter.

REFRACTIVE INDICES*

Syn. rutile	2.616		2.903
Diamond		2.417	
Stron. titanate		2.409	
Zircon	1.925		1.984
Corundum	1.762		1.770
Syn. corundum	1.762		1.770
Syn. spinel		1.730	
Spinel		1.718	
Spodumene	1.660	1.666	1.676
Tourmaline	1.624		1.644
Topaz	1.609	1.611	1.617
Beryl	1.577		1.583
Quartz	1.544		1.553
Chalcedony (moonstone)	1.535		1.539
Orthoclase (moonstone)	1.518	1.524	1.526
Plastics			
Plexiglas and lucite		1.50	
Glass (normal range)		1.48 to 1.70	
Glass (extreme range of gem imitation types)		1.44 to 1.77	
Opal		1.45	

* A single figure is given for isotropic, two for uniaxial, and three for biaxial materials. Variations are shown in the refractive index tables in the Appendix.

The colorless gemstones and substitutes with indices over the scale of the refractometer include diamond, zircon, synthetic rutile, Fabulite, doublets employing one or more parts of diamond or

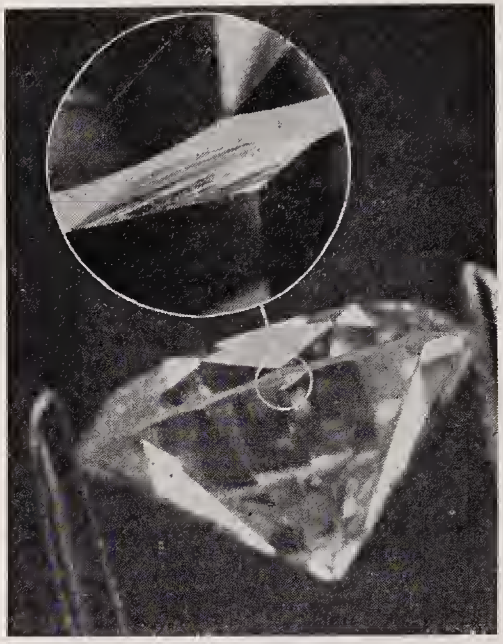

Figure 142

A shiny natural below a typically smooth, frosted, diamond girdle.

other materials with indices above the 1.81 maximum reading for the refractometer.

Frequently, jewelers feel that they can identify diamond on sight simply because of its luster. When examining well-cut clean stones under good lighting, many are seldom wrong. However, it is true also that many jewelers have been fooled by stones that, upon more careful examination, were quite obviously imitations. How may diamonds be recognized? Perhaps the most characteristic feature is the unique texture of the girdle surface on round brilliants or rounded "fancy" shapes, where the girdle has not been polished. The lathe-turning used in rounding up a diamond imparts an appearance that is not duplicated on any of its imitations. This very fine-grained surface on a finely turned girdle varies from a finely frosted to a slightly shiny reflective surface that should not be confused with any other stone. A poorer, coarser texture, caused by too-rapid bruting, is equally characteristic. The so-called bearded girdle resulting from numerous hairline fractures is never

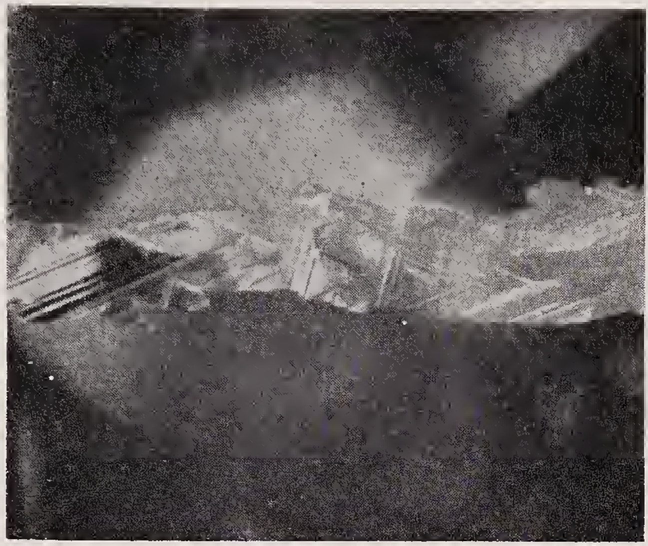

Figure 143

Trigons on a diamond crystal surface.

encountered in other gems; this is often still apparent on polished diamond girdles. In addition, a diamond frequently has "naturals," portions of the original skin of the diamond, either on the girdle or near it. On such naturals, the grooved appearance expected on the rhombic dodecahedral diamond crystal faces, or the trigons usually found on octahedral faces, are unique and not seen on diamond imitations. In addition, crystal inclusions, so-called twinning or grain lines, and evidence of cleavage are all characteristics not likely to be encountered in any of the stones often confused with diamond. Following General Electric's lead, many organizations have produced synthetic diamond grit, and General Electric has produced one-carat diamond crystals. Crystals of this size are structurally too weak to be useful, even for industrial purposes, so it still seems some time before synthetic diamond will be a problem for the gem tester.

Other properties of diamond that are useful in its identification are luster and hardness, especially as they affect the appearance of the cut stone. In other words, no gemstone has sharper facet edges or better polish than is usually encountered on gem diamonds.

Historically, the major test for diamond by jewelers has been hardness. A hardness test very carefully applied by using a diamond to scratch corundum is not too likely to harm a diamond with a wide girdle. However, if the diamond has a bearded girdle or if the girdle is knife edged, it is very easy to cause serious damage, even though it is much harder than the stone being scratched. As a result, using a diamond for a hardness test should be avoided, except when there is no other choice. If a hardness test is performed with a diamond, apply the girdle very gently to a synthetic sapphire or ruby. Diamond is so much harder that it "bites" with ease and almost no pressure is needed.

A refractive index determination is important in diamond detection, in spite of the fact that its refractive index is well above the scale of the refractometer. Thus, refractive index is utilized not by reading diamond's index on a refractometer, but by immersing stones in a medium of very high refractive index, such as methylene iodide (1.74), to determine relative relief; this is the degree to which a stone stands out from the liquid, in contrast to other materials of lower index. In this way, it is very simple to distinguish diamond from any material other than synthetic rutile and Fabulite; these may be distinguished readily by other means. Even immersing stones in water is helpful, since diamond appears almost the same as in air, whereas such substitutes as synthetic sapphire and synthetic spinel lose much of their brilliancy.

Of the stones mentioned, those with indices in the neighborhood of diamond are synthetic rutile and strontium titanate, or Fabulite. Fabulite has an index almost exactly that of diamond, but it has considerably greater fire. Synthetic rutile has an enormous dispersion of approximately .330 between the B to G Fraunhofer lines, as compared to the .044 figure for diamond. Fabulite is approximately .200. Synthetic rutile and strontium titanate both display prismatic colors to a degree well beyond that of any natural gemstone. Both of these materials are relatively soft, strontium titanate significantly softer than synthetic rutile, but each is softer than quartz or zircon. Synthetic rutile is usually listed as 6 to 6½; polished surfaces seem to resist the #6 point, but 6 scratches a fracture surface. Strontium titanate is usually listed at 6, but a knife-blade (5½ to 6) will scratch it. Neither stone is likely to exhibit a very fine polish. There is a tendency for grooved facets and for rounded facet edges that are never encountered in diamond. Even if a diamond is poorly polished, it does not have the irregularly grooved appearance to the unaided eye or the greasiness often seen in both of the other stones. However, there is no need to use a hardness test to identify either, since both are readily identified by other means, such as high dispersion and high density.

Strontium titanate, like diamond, is singly refractive, in contrast to the doubly refractive synthetic rutile. The latter has an enormous birefringence of .287; this is about 60% greater than that exhibited by that familiar example of high birefringence, the Iceland spar variety of calcite. With so high a birefringence, even with a correct orientation of the optic axis (perpendicular to the table), the stone fails to avoid an appearance of fuzziness. Doubling becomes significant at even an angle of only a degree or two to the optic axis. Synthetic rutile always has a yellowish cast in its diamond-imitating form.

Zircon, another gemstone commonly used as an imitation diamond, is also strongly birefringent. It has slightly weaker fire than diamond, and, unlike synthetic rutile, it is usually entirely without body color when used as a diamond imitation. The birefringence of zircon is much less than that of synthetic rutile, actually less than one-fifth as great. However, doubling of opposite facet junctions is usually visible under very low magnification, if a faceted zircon is observed through the bezel facets.

An unusual feature in a colorless material is zircon's characteristic absorption spectrum. Colorless material usually shows two fairly sharp lines in the red; the stronger is at 6535 and a companion usually may be seen at 6590Å. Diamond with even a slight tint of yellow usually shows the typical absorption line in the deep violet, at 4155Å. It is so near the limit of visibility that it is often missed in a casual examination, but it is a strong line in most yellowish diamonds. Zircon and synthetic rutile are readily distinguished also by the 4.70 specific gravity of colorless zircon, com-

Figure 144
Doubling of opposite facet junctions in corundum.

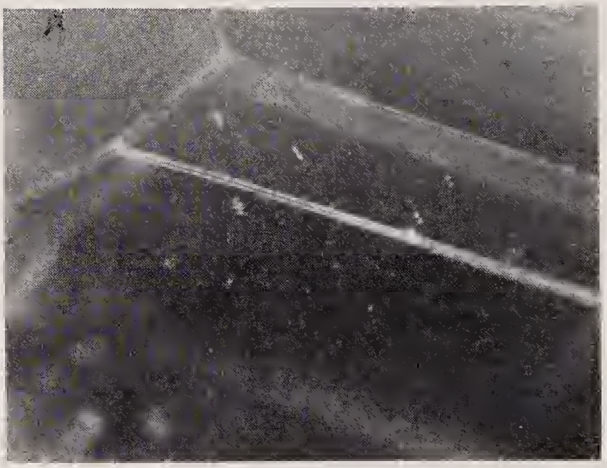

Figure 145
Doubling in tourmaline.

pared to the 4.26 of the latter. Strontium titanate is considerably higher in specific gravity than any other colorless diamond substitute, with a 5.13 specific gravity.

Although refractive index readings should be obtained on diamond substitutes other than strontium titanate, zircon, synthetic rutile and diamond and diamond doublets (and these should show a dark shadow up to the liquid line, at 1.81) there is one precau-

Figure 146
Doubling in zircon.

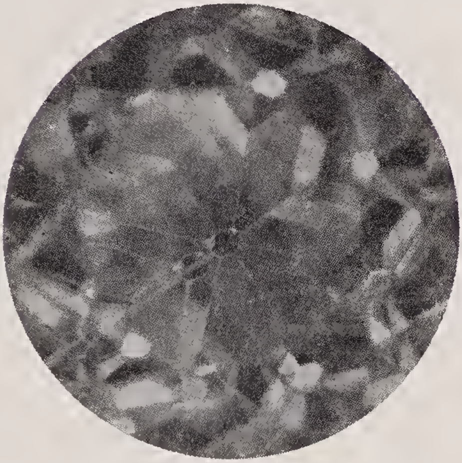

Figure 147
Doubling in synthetic rutile.

tion: diamond substitutes are frequently mounted so that a prong or side stone extending above the table of the center stone makes it impossible to use the refractometer. If such stones are diamonds, they are usually readily identified under magnification by the means explained earlier. The same is true of many of the substitutes. For example, synthetic and natural colorless sapphire, topaz and quartz should show doubling under fairly high magnification; synthetic spinel and synthetic sapphire may show bubbles. Immersion of a piece of jewelry with stones suspected of being other than diamond should make it obvious whether the relief in water or some other immersion liquid is sufficient for diamond. If it is low, it is possible to estimate its relative index by comparison with known stones such as sapphire, topaz and synthetic spinel. Although it may be difficult in some rare instances to identify the stones beyond question, it is usually a simple matter to determine whether or not they are diamonds; for the jeweler, this is often sufficient.

Often, the gemologist is called upon to identify colorless stones that are obviously too low in luster to be diamonds. Usually, they are identified beyond question by refractometer, plus one other test. This is true of colorless topaz, tourmaline, quartz, beryl and spodumene. An accurate index reading plus proof of double refraction will identify any of them, although additional tests such as specific gravity or optic character could be used to separate topaz from tourmaline, if necessary.

If the reading is 1.76 - 1.77 the situation is not as simple, for it is necessary to determine whether the colorless sapphire is natural or synthetic. Usually, magnification will disclose either the angular inclusions associated with natural sapphire or the spherical bubbles of the synthetic. In colorless sapphire the chance of flawless material is greatest. The gemologist does not have the benefit of absorption spectrum differences, fluorescence differences or curved striae as he has in some other colors; therefore, it may be necessary to utilize the technique described by Dr. Plato to detect synthetic corundum. (See Chapter X.)

Stones most commonly substituted for diamond melee are zircon, synthetic or natural colorless sapphire, or synthetic colorless spinel. Usually, it makes little or no difference whether melee is synthetic or natural colorless sapphire, since the value difference is negligible. Seldom is it worth the gemologist's time to distinguish between them, for if the melee are not diamond they have little value. If necessary, careful examination under magnification should disclose either bubbles or angular inclusions, to permit satisfactory separation. It is almost inevitable that the tester will have to assume all melee to be natural or synthetic, on the basis of clear evidence seen in a portion of the total number showing visible inclusions. If there are many synthetic sapphire melee, some are almost certain to be without visible inclusions.

The problem does not occur with synthetic vs natural colorless spinel, since the latter is virtually unknown. Rutile, strontium titanate and synthetic spinel are much more likely to be used for substitutes for fancy cut, larger diamonds. (To a diamond man, fancy cut used in this sense means any cut other than the 58-facet round brilliant or the single cut.) At a glance, a well-polished, emerald-cut synthetic spinel is often mistaken for diamond. In the usual spread emerald cut, the diamond's fire is subdued and is therefore less noticeably different from the weakly dispersive synthetic spinel. The low relief of synthetic spinel in any immersion liquid separates it from diamond. The anomalous double refraction in the pattern that is characteristic of synthetic spinel plus its distinctly higher index serves to distinguish the synthetic from near colorless natural spinel.

Palpable efforts to defraud are perhaps more commonly encountered with diamond substitutes than with most of the other gemstones. One that clearly took into account the gemtester's methods was that in which synthetic colorless spinel solitaires were mounted so that one or more prongs extended above the table, to prevent it from being placed on the refractometer. This occasionally led unwary testers to the conclusion that the stone had an index above that of the scale of the refractometer, since no reading was seen.

Diamond doublets appear rarely. Perhaps the main reason they are uncommon is the lack of suitable adhesive prior to the introduction of epoxy resins. Now, that this extremely strong adhesive is available, a flood of diamond doublets would not be too surprising. Apparently, the main problem involved in preparing such substitutes has been the expense in comparison with the yield. Careful examination under magnification discloses the plane at which the two portions are joined.

Figure 148
A thin diamond cap over a space lined with metal formed to imitate pavilion facets.

Sometimes, the appearance of a very large diamond is gained by inference, when a flat diamond is cut in the form of the crown of a brilliant or a very flat rose cut and mounted in a gypsy setting with the portion where the pavilion would be expected to lie completely concealed by the setting. In other words, a flat diamond crystal is faceted so that its depth is perhaps 15 or 20 percent of the diameter, instead of about 60 percent for a stone with a pavilion. It is mounted in a way that gives the impression of being a huge stone; in some instances, the metal seen through the stone has been cast over a mold to give the impression of facets. This deception is sometimes carried so far that an opening is left on the finger side of the ring from which protrudes a tiny portion of what appears to be the diamond's pavilion, but which is actually only a very small single-cut diamond. This same practice is sometimes employed in rings containing glass foil backs imitating diamonds.

Although it seems difficult to conceive, doublets consisting of

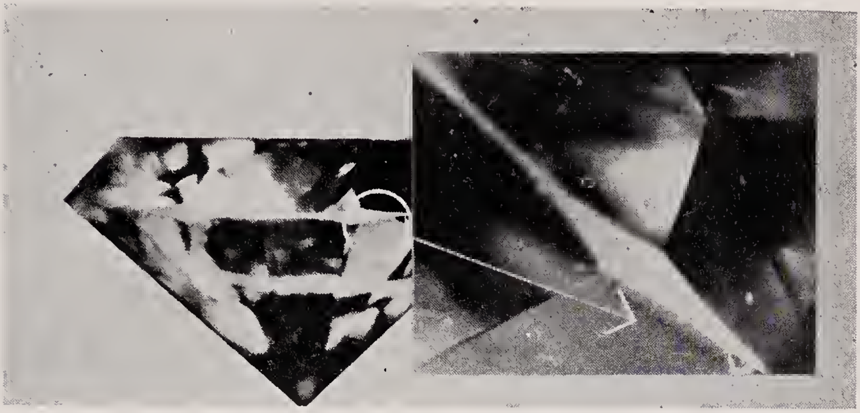

Figure 149
A diamond coated just below the girdle to improve color.

red garnet crowns and colorless glass pavilions have been used as diamond substitutes. The garnet crown imparts a fairly high luster to the top of the stone and does not absorb enough light to make a red tint apparent. It is only by turning the stone table down on white paper that the red table becomes evident. The garnet cap is invariably very thin, occupying only a small portion of the crown below the table. These are easily identified under magnification, by immersion, or by the red-ring test.

Despite the fact that rough colorless topaz and rock crystal quartz are often assumed by rock collectors to be diamonds when they are found to scratch glass, it would be almost difficult to confuse cut stones of these materials with diamonds. The rock crystal variety of quartz is much more often mistaken for diamond in the rough than is any other stone. However, it is easily identified by its hexagonal crystal form, specific gravity (2.65-2.66), and its double refraction. In addition, rock crystal shows a unique uniaxial interference figure in that the dark brushes of the figure do not cross in the center, but reach only to the edge of the innermost colored ring.

Colorless beryl and tourmaline are not common in jewelry; however, each is cut occasionally. Tourmaline's .020 birefringence, 1.624 and 1.644 refractive indices, and 3.04 specific gravity identify it readily. Doubling of opposite facet junctions should be visible under magnification, and the 1.644 reading is the constant reading.

Colorless beryl is more likely to have properties near the high end of the beryl range. Indices are often over 1.58, unless the beryl has a faint bluish tinge, then indices in the 1.57 to 1.575 range are usual. It is unlikely to be confused with other colorless stones after a careful refractometer reading is obtained.

Glass has long been employed as a diamond substitute. Although it frequently bears no more than the most superficial resemblance to its valuable counterpart, the addition of enough lead and thallium can add enough dispersion to bring the fire of glass close to that of diamond. However, the highest index for colorless glass is very low compared to diamond, since the former is rarely above 1.69.

Distinguishing between moonstone and its substitutes, synthetic spinel, plastic, the more transparent forms of chalcedony, moss agate, banded agate and a form of relatively transparent white opal, should not be difficult. Orthoclase moonstone is easily distinguished from milky chalcedony by its behavior in the polariscope. Orthoclase extinguishes every 90°, and usually its biaxial interference figure may be resolved in this cabochon material. Moonstone has a cleavage that is usually evident somewhere around the girdle, in contrast to the waxy, conchoidal fracture of chalcedony. In addition, the property values for the two stones are different in that the refractive index for chalcedony is between 1.535 and 1.54, whereas that of moonstone is about 1.518 to 1.526. With care, the distinctly lower readings are easily noted on the refractometer. Doubling of inclusions based on a .008 birefringence and higher transparency distinguish feldspar moonstone under magnification. Moonstone is not always orthoclase feldspar: sometimes it has a higher percentage of albite plagioclase feldspar than orthoclase. In this case the property values are slightly higher and more nearly those of chalcedony; however, the mere presence of doubling is sufficient to distinguish between them. The quality of the floating blue light or adularescence in moonstone is never encountered in chalcedony. The synthetic spinel that imitates moonstone has been heat treated to cause some of the excess aluminum oxide separate out and crystallize as hexagonal alumina, giving the stone a milky appearance and an oriented reflectivity. The refractive index and specific gravity of synthetic spinel are so much higher than those of moonstone that there is no difficulty in separating the two. Plastic with the same type of floating light is easily identified by its very low specific gravity. Comparable opal lacks a floating light effect; however, the type that is sometimes referred to as water opal or Mexican opal is sometimes colorless and is marked by a vague play of color throughout the stone. The very low refractice index of about 1.45, but which may be even lower than 1.40, and the low specific gravity (about 2.00) serve to identify opal readily.

PROPERTY TABLES FOR COLORLESS MATERIALS IN ORDER OF DESCENDING INDICES

Name	**Polar.**	**S.G.**	**Hard.**	**Additional**
Syn. rutile	D	4.26	6-6.5	doubling, fire
Diamond	S	3.52	10	girdle, cleavage
Stron. titanate	S	5.13	5.5	fire, rounded facet edges
Zircon	D	4.70	7.5	spectrum, doubling
Corundum	D	4.00	9	inclusions
Syn. corundum	D	4.00	9	inclusions
Syn. spinel	S (anom.)	3.64	8	strain pattern
Spinel	S	3.60	8	very rare
Spodumene	D	3.18	6-7	cleavage, biaxial +
Tourmaline	D	3.04	7-7.5	bire.
Topaz	D	3.53	8	cleavage
Beryl	D	2.70	7.5-8	uniaxial —
Quartz	D	2.66	7	interference figure
Chalcedony (moonstone)	D (light)	2.60	6.5-7	waxy fracture (semitransparent)
Moonstone	D	2.56	6-6.5	cleavage, adularescence
Plastics	S (anom.)	<2	<3	heft light
Glass	S	2.3-4.5	5	molded?
Opal	S	2.00	6	play of color?

Mention must be made in a section on colorless, transparent stones of a large variety of materials, which occur naturally in a transparent form, that are cut principally by amateur lapidaries, and are sought by those who collect stones of any species in a faceted form. It is very difficult to keep abreast with all of the possibilities, since, whenever any stone with a hardness of 2 or more is found in a colorless or transparent form, it is sure to be cut by someone. In addition to spodumene, beryl, tourmaline, and topaz, there are such unusual materials as spinel, benitoite, beryllonite, augelite, hambergite, petalite, rhodizite, danburite, apatite, orthoclase (faceted), jadeite, euclase, fluorite, phenakite, pollucite, amblygonite, labradorite, bleached brazilionite, leucite, scapolite, scheelite, and numerous others that have been cut by, or for, collectors to amaze friends and confound many gemologists. A brief table of the principle properties of these stones is given below. All are described more fully in Chapter XV.

All of those stones listed in the following table have either been encountered in one or both of the GIA Laboratories or are sufficiently durable to qualify as gem materials.

	Refractive Indices			Specific Gravity
Scheelite	1.918		1.934	6.12
Benitoite	1.757		1.804	3.64
Rhodizite		1.69		3.40
Jadeite	1.654	1.659	1.667	3.34
Phenakite	1.654		1.670	2.95
Euclase	1.654	1.657	1.673	3.10
Apatite	1.642		1.646	3.18
Danburite	1.630	1.633	1.636	3.00
Amblygonite	1.612	1.623	1.636	3.02
Brazilianite	1.602	1.609	1.623	2.99
Augelite	1.574	1.576	1.588	2.70
Labradorite	1.559	1.563	1.568	2.70
Hambergite	1.555	1.586	1.625	2.35
Beryllonite	1.552	1.558	1.562	2.85
Scapolite	1.550		1.572	2.68
Pollucite		1.525		2.92
Orthoclase	1.518	1.524	1.526	2.56
Leucite		1.508		2.50
Petalite	1.502	1.510	1.518	2.40
Fluorite		1.434		3.18

Chapter XXIV

The Identification of Nontransparent Violet and Blue Gemstones and Their Substitutes

The important gem materials occuring in a nontransparent violet and blue form include natural and synthetic star sapphires and other star substitutes, turquoise and its substitutes, and lapis-lazuli and its substitutes. Violet and grayish-blue jadeite, dyed and natural blue chalcedony, and opal with an all-blue play of color are also included.

First Test. The nontransparent unknown is examined by unaided eye or a low power loupe, to detect any unique or unusual identifying characteristics or to eliminate many of the possibilities. Examine luster; nature of cleavage or fracture; luster on breaks, if any; optical phenomena, such as chatoyancy or asterism; quality of polish; and any other features. Any of the following characteristics may be of use in reducing the number of possibilities:

Intense dark blue gem with flecks of metallic yellow suggests lazurite (lapis-lazuli), or synthetic spinel.
Intense light blue color suggests turquoise or a substitute.
Dull or waxy luster on a fracture surface of a translucent blue gem suggests chalcedony quartz.
A six-rayed star suggests corundum (star sapphire), synthetic star sapphire or an imitation.
A coated back on a star stone indicates a foil back.
A play of color suggests opal.

Warmth to the touch (compared to the cold feel of crystalline materials) suggests a plastic, glass, or opal.

Second Test. If the unknown has a flat polished face, take a normal refractive index reading. In the more likely case that it is cut *en cabochon* and has only curved surfaces, take a spot reading. Be sure that the spot is reduced to no greater than two or three scale divisions in diameter, for greatest accuracy in reading. Although the refractive index taken by this method is not readable to quite the accuracy of the flat-facet method, it should reduce the number of possibilities materially. If no index reading is possible, the other properties of these gemstones will prove of value in identifying the stone.

Name	R.I.	S.G.	Hard.	Additional
Corundum	1.762-1.770	4.0	9	inclusions
Syn. corundum	1.762-1.770	4.0	9	inclusions
Azurite	1.730-1.840	3.80	3.5-4	acid, effervescent
Syn. spinel	1.728	3.52	8	vivid color
Dumortierite	1.678-1.689	3.30	7	blue or violet
Diopside	1.675-1.701	3.29	5-6	dark blue
Jadeite	1.654-1.667	3.34	6.5-7	spectrum
Smithsonite	1.620-1.850	4.30	5	acid, effervescent
Turquoise	1.610-1.650	2.75	5-6	light blue
Lazulite	1.610-1.640	3.09	5-6	dark blue
Odontolite	1.600-1.610	3.10	5	acid, effervescent
Quartz	1.544-1.553	2.66	7	foil back
Chalcedony	1.535-1.539	2.60	6.5-7	waxy fracture
Stichtite	1.516-1.542	2.16	1.5-2	acid, effervescent
Lapis-lazuli	1.50	2.75	5-6	pyrite
Sodalite	1.48	2.24	5-6	
Plastic	1.49 to 1.67	<2.0	<3	soft
Glass (normal)	1.48 to 1.70	2.3-4.5	5	bubbles
Opal (black opal)	1.45	2.15	5-6.5	play of color

Natural blue star sapphire is usually almost unmistakable. The essential inclusions usually impart a silkiness that often is concentrated in an obvious pattern of hexagonal zoning. "Fingerprints" and other natural inclusions are usually visible under low magnification. Linde and German (Gemma) star sapphires are characterized by their near opacity and by such a concentration of minute inclusions that a star is visible even in very diffused light. The needlelike inclusions are not resolvable individually at less than about 50X. Bubbles are visible in great numbers, if a strong beam is directed at the cabochon from the side and the point of examination (under 10X to 30X) is outside the direct path of the beam. Curved lines are usually visible too. German synthetic stars have a tight circular bull's-eye pattern on the flat base. Circular banding is seldom visible on the base of Linde stars. The use of short-wave ultra-violet light and spectroscopy, to distinguish between natural and synthetic blue star sapphires, is explained in Chapter X. German stars are usually more transparent and show the Plato effect readily.

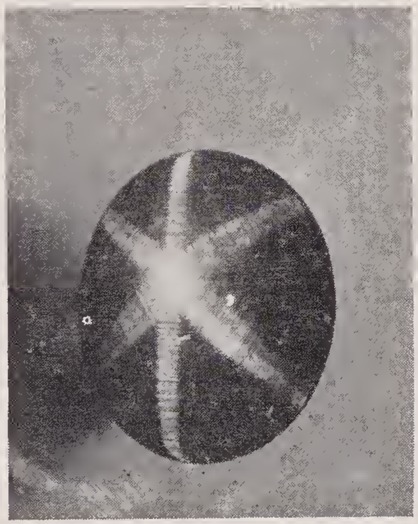

Figure 150
A synthetic sapphire backed by lined metal to simulate a natural star.

Foil backed star quartz and foil backed synthetic corundum star imitations are included in the nontransparent section because no light is transmitted directly through them from top to bottom. They are easily detected by inspection. The quartz is almost colorless from the side, and the transparent synthetic is given a star effect by engraved lines on its flat base or on a metal mirror. It bears little resemblance to a natural star because of the absence of the luster or sheen caused by needlelike inclusions.

There are several forms of natural star sapphire doublets that have been encountered from time to time. They are particularly likely to trap the unwary because of the obviously natural appearance of the portion in view above the setting. Usually, the top is a white to blue-gray star sapphire with sharp star but enough transparency for the blue color from beneath to impart its color to the whole. The color may come from a blue cement, a blue lower piece of dyed or naturally colored corundum, or of synthetic corundum with appropriate color. Careful use of magnification and examination of the base serves to detect the deception. In blue doublets, cobalt coloring in the cement or in a dyed back may show red through a color filter, or an arborescent pattern or bubbles may appear in the cement layer. The back may be too transparent, show bubbles, or show dye introduced into cracks by quenching a heated stone in the dye.

There are many processes by which inferior turquoise is treated to improve appearance and durability. For many years, chalky turquoise with a very low specific gravity and high porosity has been treated with paraffin, or various oils or other substances to deepen the color materially and to fill the pores. This substitute for fine-quality turquoise is very inferior, since it soon loses its attractive color and takes on a greenish cast. Paraffin impregnated material often becomes mottled with whitish spots. Detergents may remove the wax and reduce it nearly to its original chalk-like consistency. Turquoise that has been treated with wax, plastic, or sodium silicate is distinguished by a considerably lower specific gravity than the usual figure of 2.75 to 2.80 for fine, compact turquoise. Impregnated material may be as low as 2.30, but 2.4 to 2.7 is more common. Impregnation of porous material with plastic or sodium silicate make a much more satisfactory substitute, because it is not only durable but the color-retention properties are infinitely superior to those of oil- or paraffin-impregnated turquoise.

Sometimes, blue powdered material, either turquoise, various salts of copper or other metals, are compacted under heat and pressure to form a tabletlike substitute. It has been sold under such incorrect names as "reconstituted turquoise," and "synthetic turquoise." This imitation is different in structure under magnification from natural turquoise. It has a granular, porcelainlike appearance, in contrast to turquoise's very fine-grained structure. Under magnification, grains of a blue material darker than turquoise are visible in a lighter groundmass of distinct grains. Some has a spiderweb pattern of brown to black, simulating matrix. Three different types tested in the GIA Laboratories had specific gravities of 2.75, 2.58, and 2.06. This kind of imitation usually contains a copper compound to produce the blue color. The copper salts used are soluble in hydrochloric acid, so a tiny drop of acid (one part concentrated acid to two parts of water is a satisfactory concentration) quickly turns greenish-yellow. This is obvious on white tissue used to wipe off the spot, if not obvious immediately on contact.

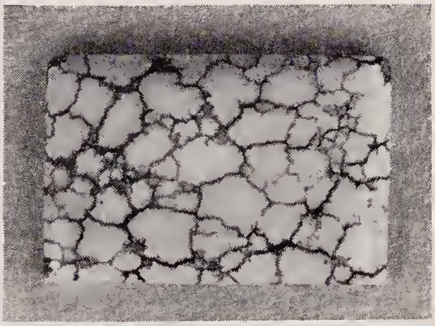

Figure 151

Polished cabochon of natural spider-web turquoise.

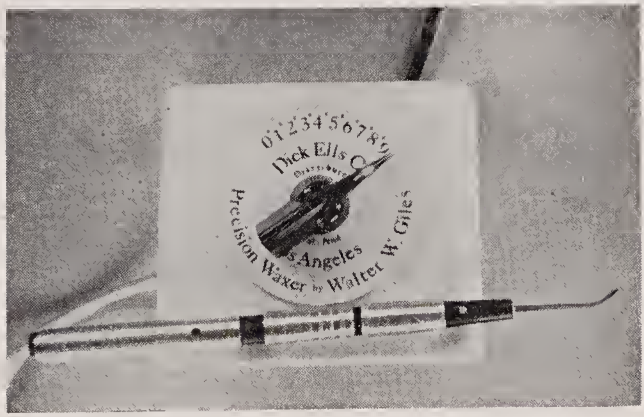

Figure 152

An electrically heated, metal point useful for testing.

Wax, paraffin or plastic impregnation can be detected readily by the use of an electrically heated point, such as a wax modeling tool, the point of a soldering tool or even a red-hot needle. If a red-hot point is brought close to wax-impregnated turquoise, the wax runs ahead of the needle and is readily visible under magnification. Material mottled with white or uniformly whitened at the surface regains its blue color under the hot point when the paraffin or wax resets. The point does not usually need to be touched against the surface to cause the wax or paraffin to liquefy. To detect plastic impregnation, it is necessary to bring the point in contact with the stone at some inconspicuous spot and to note the odor given off by the scorched material. The acrid odor of plastic is distinctive and should be easily recognized. Sodium-silicate-treated material gives no detectable odor, so the low density is the only proof of treatment.

By the spot method, the turquoise reading is characteristically just over 1.60; figures above 1.61 are not usually encountered. Gem turquoise is very compact and has an almost vitreous appearance when well polished. The glass substitute for it can be an excellent imitation, particularly in a well-polished cabochon; however, it is possible to detect the vitreous luster on small conchoidal fracture surfaces, in contrast to the dull luster of small fractures on turquoise. In addition, it is usually possible to see bubbles just beneath the surface of the glass or hemispherical holes in the surface.

A gemstone that may be confused with turquoise is chrysocolla quartz (chalcedony). It is an attractive gemstone when it contains enough chrysocolla to assume the beautiful blue color of that mineral but not enough to have the characteristics of pure chrysocolla, such as a hardness of 2 to 4 and a specific gravity near 2.20. Although some fine chrysocolla quartz resembles turquoise closely, it has the properties of chalcedony (refractive index approximately 1.535 to 1.54 and specific gravity at or below 2.6). Chalcedony, apparently, has not been dyed successfully to a color closely resembling turquoise. Chrysocolla quartz is usually more transparent than turquoise.

Odontolite, once well known in Europe as "bone" or "fossil turquoise," is almost unknown in America. It is a fossilized form of vertebrate bones or teeth colored blue by the mineral vivianite. Odontolite was once mined extensively from sedimentary beds in southern France for use as a turquoise substitute. It is easily distinguished from turquoise, for it effervesces with a drop of hydrochloric acid, whereas turquoise is inert. Its specific gravity is slightly over 3.0, and it has a structure under magnification characteristic of either tooth or bone.

There the only a few stones that are likely to be confused with lapis-lazuli. The one bearing the closest resemblance in appearance is the most recently introduced substitute, sintered synthetic spinel. This type is made by heating magnesium and aluminum oxides with cobalt oxide to a high temperature for a protracted period (but a temperature well below the melting point of spinel). The resulting crystalline mass has the properties of synthetic spinel, except that pore spaces caused by failure of the powder to melt reduces specific gravity to 3.52. Unless the stone is well polished, the 1.725 index may be difficult to see by the normal method, but a good idea of its position should be obtained from the spot method. The cobalt coloring imparts a bright-red color to the stone under the emerald filter; in contrast to the low intensity of brownish-red for lapis. The pyrite of lapis is sometimes imitated by gold added to this synthetic. The absorption spectrum of the sintered material differs somewhat from the transparent blue synthetic spinel. The usual cobalt lines appear in a weaker, more diffused form as a broad smudge in the 5300 to 6000Å area. Two stronger bands are centered near 6500 and 4800Å, with a weaker band near 4500Å.

Lapis-lazuli is actually a rock composed of lazurite and hauynite, plus sodalite as its blue constituents, with a number of other minerals providing constituents of other colors. One of the others that is almost always present is pyrite, the metallic yellow specks one associates with lapis-lazuli. Another common constituent is diopside.

Sodalite in a relatively pure form is, in a sense, regarded as a substitute for lapis. It is more translucent than lapis-lazuli and seems to lack the vividness of color that is associated with fine-quality lapis.

The specific gravity of lapis is about 2.75, but it varies from less than 2.7 to slightly over 3.0, depending on the abundance of the appreciably denser pyrite included; fine-quality material is usually about 2.8. On the other hand, pure sodalite has a specific gravity of about 2.25. The refractive index for lapis is approximately 1.50, but often the presence of diopside accounts for a second reading also visible near 1.68. Sodalite is usually about 1.48.

The dyed jasper once widely sold incorrectly as "Swiss lapis" often bears no more than the vaguest resemblance to lapis, but occasionally it is very similar in appearance. The color is seldom vivid and the dyed jasper lacks the pyrite that usually is seen in lapis-lazuli. The approximately 1.54 index of jasper easily distinguishes it from lapis.

Lazulite is sometimes quite similar to lapis-lazuli in appearance but actually more often resembles sodalite. Better qualities of lazulite are easily distinguished from lapis by the lack of pyrite in a material that has a specific gravity near 3.1; in other words, if lapis is 3.0 or over in specific gravity, pyrite would have to be abundant. In addition, the refractive indices are much higher, at 1.61 and 1.64. Usually, sodalite and lazulite contain an abundance of white material that is characteristic only of inferior lapis.

Dumortierite is a dark-blue to blue-violet mineral that resembles lazulite and sodalite more than it does lapis-lazuli; it is easily distinguished by its index (near 1.68-1.69) and by its specific gravity (3.30) near the 3.32 liquid.

Violane, a rich violetish-blue variety of diopside, is sometimes cut in cabochon form. Its refractive indices are 1.675 and 1.701, and the specific gravity is about 3.29. The birefringence is approximately .026, about twice that of dumortierite. This should be evident by rotating a Polaroid plate in front of the scale while viewing the spot at the approximate point of the reading. Violane is 5-6 in hardness, compared to 7 for dumortierite.

Light grayish-blue or bluish-gray jadeite is used for jewelry and for carvings. The characteristic 1.65 refractive index, specific gravity near that of methylene iodide, and the strong 4370Å absorption line in the violet serve to identify it conclusively.

Smithsonite, which resembles translucent chrysocolla quartz or a light blue agate, is cut primarily for ornamental objects. Its effervescence to hydrochloric acid and its great birefringence indicated by refractive indices of 1.62 and 1.81 + identify it readily.

Blue aventurine glass with tetrahedral copper crystals is similar to goldstone. It is unmistakable in appearance; a very poor imitation of lapis-lazuli. It has a refractive index near 1.55 and a specific gravity near 2.65.

Amethystine quartz in a nontransparent form is often used in carvings and less often in a cabochon form for jewelry. Usually, it has an attractive violet-and-white banded pattern.

Stichtite occurs in semitranslucent light violetish-red and is used for carvings and it is also fashioned into cabochons. It is readily identified by its low hardness of 1.5 to 2 and it is effervescent to hydrochloric acid. The refractive index may be difficult to obtain because of poor polish (1.516 to 1.542); specific gravity is near 2.16.

Opal with a play of color limited to blue is included here, because it gives the impression of being a blue stone from any direction. It is easily identified by its 1.45 refractive index and specific gravity of 2.15.

Chapter XXV

The Identification of Nontransparent Green Gemstones and Their Substitutes

This chapter could be subtitled "The Identification of Jade and Jade Substitutes," because the majority of the nontransparent green stones have been used as jade substitutes.

Two distinct minerals are correctly called jade; jadeite, a member of the pyroxene group of minerals, and nephrite, a mineral variety related to actinolite and tremolite, both members of the amphibole group of minerals. Both jadeite and nephrite have two different uses and there are two groups of jade substances depending on those uses. The jade used for strictly jewelry purposes is substituted for by a number of other green minerals, including grossularite garnet, idocrase (or californite), nontransparent emerald, synthetic emerald, aventurine quartz, glass, serpentine, fluorite, dyed onyx marble (dyed calcite in the form of onyx), prehnite and plastic. In the other category is the type of jade used for carvings. The substitutes for jadeite or nephrite in this classification include the soapstone or steatite varieties of talc; sillimanite, or fibrolite; pseudophite; agalmatolite (better known as pagoda stone); saussurite and verdite as well as many of the materials used in jewelry. In addition to jade and the jade substitutes there are a number of nontransparent green gem materials such as green star sapphire, opaquish green chrysoberyl cat's-eye, malachite and others.

First Test. The nontransparent unknown is examined by unaided eye or a low power loupe, to detect any unique or unusual identifying characteristics or to eliminate many of the possibilities. Examine luster; nature of cleavage or fracture; luster on the breaks; optical phenomena, such as chatoyancy or asterism; quality of polish; and any other features. Any of the following characteristics may be of use in reducing the number of possibilities:

A six-rayed star suggests corundum (star sapphire).

A single sharp band of reflected light across the crest of a gem with a silky luster suggests chrysoberyl (cat's-eye), quartz, tourmaline, or glass.

A light and dark yellowish-green agatelike banding in an opaque green stone suggests malachite.

A play of color suggests opal.

Warmth to the touch (compared to the cold feel of crystalline materials) suggests a plastic, glass, or opal.

A "shredded" or gridlike appearance in a light blue-green semitranslucent gem suggests amazonite (microcline feldspar).

Dull or waxy luster on a fracture surface of a translucent green gem suggests chalcedony quartz.

Second Test. If the unknown has a flat polished facet, take a normal refractive index reading. In the more likely case that it is cut *en cabochon* and has only curved surfaces, take a spot reading. Be sure that the spot is reduced to no greater than two or three scale divisions in diameter, for greatest accuracy in reading. Although the refractive index taken by this method is not readable to quite the accuracy of the flat-facet method, it should suffice to reduce the number of possibilities materially. If no index reading is possible, the other properties of these gemstones will prove of value in identifying the stone.

By far the most valuable and coveted of the two jades is furnished by jadeite. When colored an intense green by chromium, jadeite brings the highest prices and is greatly desired by collectors. It occurs from fairly dark bluish-green to a very intense, almost emerald-green, which is usually slightly more yellowish-green than emerald. In the finest quality, so-called Imperial jade, is almost transparent. Often, the green color occurs as patches in a white background. The refractive index of jadeite is usually given as

1.654 to 1.667; however, on readings obtained by the spot method, a 1.65 figure is the one usually expected. The specific gravity is almost exactly that of methylene iodide, the 3.32 liquid. The spectroscope is an exceedingly valuable tool when employed in the identification of jadeite: not only does it serve to detect green dye in stones cut for jewelry, but it is useful in distinguishing between jadeite and substitutes in large carvings as well as small cabochons. Stones that are light enough in color so that the blue and violet end of the spectrum is not entirely absorbed show a strong, sharp line at 4370Å.

Name	**R.I.**	**S.G.**	**Hard.**	**Additional**
Corundum	1.762-1.770	4.00	9	silk, spectrum
Chrysoberyl	1.746-1.755	3.73	8.5	silk, spectrum
Grossularite	1.725	3.50	7	black inclusions
Idocrase	1.713-1.718	3.40	6.5	greasy
Saussurite	1.700-1.710	3.20	6.5-7	
Malachite	1.660-1.910	3.3-3.9	3.5-4	banded
Jadeite	1.654-1.667	3.34	6.5-7	spectrum
Sillimanite	1.659-1.680	3.21	6-7	
Chlorastrolite	1.650-1.660	3.20	5-6	fibrous
Smithsonite	1.620-1.850	4.30	5	acid effervescent
Tourmaline	1.624-1.644	3.08	7-7.5	cat's-eye?
Prehnite	1.615-1.646	2.88	6	near transparent
Turquoise	1.610-1.650	2.8	6-6.5	dull fracture
Nephrite	1.606-1.632	2.95	6-6.5	
Verdite	1.580	2.90	3	dark green
Beryl	1.570-1.580	2.71	8	inclusions
Pseudophite	1.570-1.580	2.70	2.5	R.I. vague
Syn. emerald	1.561-1.565	2.66	8	fluorescent
Variscite	1.560-1.590	2.50	4-5	
Serpentine	1.560-1.570	2.57	2.5-5.5	greasy
Agalmatolite	1.550-1.600	2.80	2.5	R.I. vague
Quartz	1.544-1.553	2.66	7	inclusions
Steatite	1.540-1.590	2.75	1-2.5	very soft
Chalcedony	1.535-1.539	2.60	6.5-7	waxy fracture
Microcline	1.522-1.530	2.56	6-6.5	cleavage
Plastic	1.49 to 1.67	<2	<3	
Glass (normal)	1.48 to 1.70	2.3 to 4.5	5	molded?
Opal	1.450	2.15	5-6.5	
Fluorite	1.434	3.18	4	cleavage

When nephrite powder is tested for refractive indices under the polarizing microscope, the exact determinations are usually 1.606 to 1.632, but the spot method gives a result that is usually 1.61. The specific gravity is often near the bromoform reading, but slightly above it. Bromoform has a specific gravity of 2.89, and nephrite is usually approximately 2.95, although readings slightly above 3.00 have been recorded. The only variety that is likely to be confused with fine jadeite is the apple-green material found in Wyoming. This type of Wyoming jade has a rich-green color, but it is slightly lower in intensity than the emerald-green of fine jadeite. Other green nephrite is usually a dull blackish (spinach-colored) green.

Of the gemstones likely to be confused with jade, a prominent one is that misnamed "Transvaal," or "South African jade," the green translucent variety of grossularite garnet; it is easily separated from jade by its 1.725 refractive index. Jadelike grossularite usually contains small black specks visible to the unaided eye. Although it is singly refractive, in contrast to the doubly refractive nature of jadeite, this is often impossible to determine in the polariscope. Grossularite fluoresces orange under X-rays. In appearance, "South African" or "Transvaal jade" is much more nearly comparable to the Wyoming nephrite than to jadeite.

The bowenite variety of serpentine, both harder and denser than the usual serpentine, is also richer in color and much more reminiscent of jade. In addition, the williamsite variety has an attractive green color, and common serpentine is sometimes dyed to a richer color that resembles fine jadeite. Whether dyed or naturally green, serpentine has a greasy appearance that is characteristic. It is more transparent than most jadeite. The californite variety of idocrase has a somewhat similar appearance, but its luster is much higher. Serpentine is yellow, greenish-yellow or yellowish-green. In a yellow to greenish-yellow form, it is often carved in the form of ash trays and figurines. Serpentine is identified by its refractive indices (in the vicinity of 1.56), and specific gravity (2.2 to 2.4 for normal serpentine and 2.5 to 2.6 for bowenite). The greenish-yellow variety is usually nearer 1.54 in index. It shows a fairly strong absorption band at about 4600-4700Å. Normal serpentine is distinctly less hard (2.5-4) than bowenite (5.5-6).

Much more important than any other materials used as a substitute for fine jadeite are low quality jadeite dyed to a fine green, and jadeite triplets. Pale jadeite may be dyed a rich emerald-green, making it appear many times as valuable. This substitute is prepared by subjecting light colored inexpensive jadeite to an organic dye. It is detected either by causing the color to fade through the use of an oxidizing agent, such as nitric acid, or, without harm to the stone, by the spectroscope. Three absorption lines in the red portion of the spectrum of naturally colored green jadeite distinguish it from the dyed type that shows a smudged band. They are illustrated in the spectra table in Chapter XIII. To date, the dye used has faded rapidly; often, it becomes undetectable after a year or less. A partially faded piece shows the dye lines in the spectrum, if light is passed through as thick a section of the stone as possible. There are several typical spectra of natural and dyed jadeite in Chapter XIII.

The other type of imitation is made by cutting a cabochon of translucent white jadeite and a thin hollow cabochon of the same shape to fit as a slightly larger cap over the first cabochon, plus a flat disc of the same material for the back. The jadeite shell is filled with an intense, emerald-green, jellylike substance and the cabochon is forced into the shell, so that the green coloring is evident. Then the flat disc is applied to the back with an adhesive. The result is a beautiful, translucent green triplet that closely resembles fine jadeite in appearance. It is easily identified by bubbles in the jellylike layer, and the contact zone between the hollow cabochon and the flat back is also visible, if unmounted. If the assembly is mounted, the back disc is often covered to hide the deception. Mountings with covered backs are suspect. Such triplets show the dyed jadeite spectrum.

Neither emerald nor Chatham synthetic emerald are considered as jade substitutes, but in translucent form they are widely used in jewelry. Both are usually more transparent than jadeite, but this is not a dependable test, since the finest Imperial jade is sometimes highly transparent, and heavily flawed synthetic and natural emer-

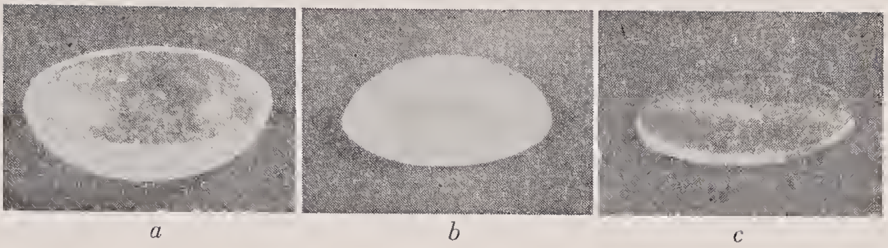

Figure 153
A three-part substitute for Imperial jade made by sandwiching an emerald-green material between parts a and b. C seals the combination.

ald may be nearly opaque. In appearance, natural emerald may bear a marked resemblance to fine jadeite. The Chatham material, however, has a distinctly bluish cast. Both are easily distinguished from jadeite by refractive index, specific gravity, or by the dichroism of both synthetic and natural emerald.

Natural emerald usually has an index in the vicinity of 1.58, distinctly above the approximately 1.565 of the Chatham product. They are readily separated by a 2.67 liquid, in which the synthetic floats and the natural sinks, unless the latter contains many voids. Inclusions are distinctly different, with the natural usually showing three-phase inclusions and the synthetic, wisp-like or veil-like inclusions. (See Chapter X.) The fluorescence of the translucent Chatham synthetic under long-wave ultra-violet in a dark room is particularly evident, in contrast to the natural.

Aventurine quartz with green fuchsite mica inclusions is another rich-green material that is easily mistaken for nephrite in appearance. It has been sold as "Regal jade" and by many other names, such as "Indian jade," implying that it is a natural jade material. However, its lower refractive indices (1.544 and 1.553) and specific gravity (between 2.65 and 2.66) distinguish it immediately from either jadeite or nephrite. Another variety of quartz is a more evenly colored yellowish-green semitranslucent type sometimes called buddstone. It has the usual crystalline quartz properties. Chrysoprase, a yellowish-green chalcedony, has even lower properties than aventurine, as does dyed green chalcedony; the latter has a characteristic absorption spectrum, which is shown in Chapter XIII.

Idocrase, or californite, resembles nephrite more nearly than it does jadeite, but it is easily distinguished from either by the fact that it has a higher refractive index and specific gravity. The specific gravity is too close to that of jadeite to be used as a distinguishing test, however. The refractive index is in the 1.70 to 1.71 range and the specific gravity is 3.40; it usually sinks slowly in methylene iodide (3.32). Idocrase has a greasy, dull-green color and it is usually fairly translucent — much more so than most nephrite. Idocrase shows a distinct line in the blue portion of the spectrum, at about 4630Å; this is often helpful in identifying unpolished material.

Prehnite, which has properties very close to those of nephrite, is an exceedingly pale-green stone that is usually much more transparent than nephrite.

Microcline feldspar (amazonite) has a distinctive appearance; at a glance it may be confused with jadeite or Wyoming nephrite. Amazonite has a bluish-green color distributed in a pattern that resembles that of coarse loosely woven linen fabric. The color seems to be interrupted by parallel sets of whitish streaks. Its very low specific gravity (2.56) and refractive indices (1.522 and 1.530) distinguish it easily from either type of jade. In addition, it is characterized by a strong two-way cleavage pattern, with one direction almost at right angles to the other. Shiny reflections are seen as a sheen in certain directions.

Glass sometimes is fashioned to make very excellent imitations of jadeite and nephrite. Such imitations are detected by the vitreous luster on tiny fracture surfaces and by the highly dependable presence of gas bubbles when examined under fairly high magnification.

The low specific gravity of plastic easily distinguishes it from jade or other jadelike minerals. They yield easily to a razor blade or pin.

Chlorastrolite, a dark-green semitranslucent mineral is rarely used as a gemstone. It shows a radial fibrous structure in semispherical grains. Its color is darker and less vivid than that of malachite, which it resembles somewhat. Chlorastrolite is distinguished by an index near 1.66 and specific gravity near 3.2.

Of the other materials used as jade substitutes, mostly for carvings, few are of particular interest to the gemologist; however, a brief consideration is in order in a discussion of the identification of jade and jadelike materials.

The greenish variety of smithsonite is easily identified by its enormous birefringence (1.62 to 1.81+), which is evident on a spot reading when a Polaroid plate is rotated before the eyepiece of the refractometer. It also has a very high specific gravity (approximately 4.3 to 4.35). Smithsonite is attacked readily by hydrochloric acid, effervescing strongly.

Pseudophite is better known as "Styrian jade," because of its original locality of Styria, Austria. It has properties very closely akin to those of serpentine, with a specific gravity of about 2.7 and a refractive index near 1.57. It is distinguished from serpentine by its even lower hardness (approximately 2); the fingernail will scratch it.

Agalmatolite, or pagoda stone, has a specific gravity of about 2.8 and a hardness of 2.5; it is more a rock than a mineral. It is more likely to be confused with soapstone than with any other material, and unlikely to be confused with jade.

Saussurite, really a type of zoisite, has an index of about 1.7, distinctly higher than those of jadeite or nephrite, and a specific gravity of about 3.2. The hardness is 6.5.

Fluorite is used fairly frequently as a material for carving by the Chinese; it has a very low refractive index (1.43), a hardness of 4, and the excellent cleavage is usually evident, even in a carved stone.

Steatite, or soapstone is usually gray or white, but often has a greenish cast. It is used almost exclusively for inexpensive carved objects. Soapstone is characterized by a soapy feel and very low hardness. Although it is a massive variety of talc, the softest mineral on the Mohs' scale, impurities often raise its hardness to 2 or 2.5. However, a fingernail usually will scratch it. Any refractive index reading is sure to be vague. It usually appears nearer the high end of the 1.54-1.59 refractive index spread. Specific gravity is near 2.75.

Sillimanite, or fibrolite, in a jadelike form is not commonly employed for either gem or ornamental use. It is a grayish-green in color and shares with jade a fibrous structure. In its compact form this mineral has properties close to those of jadeite. Its refractive indices are just slightly higher (1.659-1.680 to jadeite's 1.654-1.667) and its specific gravity is lower (single crystal is 3.23-3.24, whereas the jadelike type is usually slightly below 3.2; jadeite is near 3.34, although it may barely float in the 3.32 liquid). Fibrolite lacks the 4370Å line that characterizes jadeite's absorption spectrum.

Verdite is really a clay with an impregnation of fuchsite, the green chrome mica that also colors aventurine quartz. The refractive index is slightly above that of serpentine, at about 1.58, and its density is approximately 2.8 to 2.9.

There are a number of translucent to opaque green gemstones that are neither jade nor jade substitutes.

Star sapphire is exceedingly rare in a green color. If encountered, its star, and 1.76-1.77 refractive indices, serve to identify it. Green chatoyant chrysoberyl is less rare and often nontransparent. A refractive index reading at about 1.75 and its silky luster are characteristic. Some other green chatoyant stones may be translucent but of the other natural green cat's-eyes, only tourmaline and dyed tiger's-eye or quartz cat's-eye, are likely to contain such an abundance of needlelike inclusions that they approach opacity. Indices of 1.624 and 1.644 identify tourmaline, and the 1.54 refractive index plus 2.65 to 2.66 specific gravity in a natural stone identify quartz.

Glass or plastics are warm to the touch. Glass cat's-eye imitations contain bubbles in abundance and plastics are both soft and very light to the "heft."

Some turquoise is likely to be bluish-green in color. Often this is formerly blue porous material that was once oiled or waxed, and has since accumulated dirt, soap or skin oils in pore spaces, causing discoloration. Dull luster on fracture surfaces, plus a 1.60 or 1.61 refractive index identifies turquoise. Variscite resembles turquoise in appearance, except that it is a light yellow-green to a medium-green color. It is usually accompanied by a variety of other phosphates such as the yellow crandallite, greenish wardite, and colorless gordonite. Indices are 1.56 and 1.59, which serve to distinguish it from turquoise. When compact, the specific gravity is near 2.5, and may be as much as 2.55, but like turquoise, porous material may be significantly below 2.5. The hardness may be nearly 5 in compact material, but below 4 in porous variscite.

Malachite is usually banded in an agatelike structure in light and dark green. It may show a radial fibrous structure, with a chatoyant sheen from the lustrous fibers. Malachite has a green streak. It effervesces under hydrochloric acid. The wide birefringence (indices 1.66 and 1.91) is evident if a Polaroid plate is rotated in front of the scale during a spot reading. As the plate is rotated, the shadowed area's maximum extension moves back and forth from 1.66 to the limit of the scale at 1.81. Specific gravity varies from 3.95 to less than 3.30 depending on porosity. Gem material is usually near the former. The only materials with which it might be confused are chlorastrolite, glass and plastic. Chlorastrolite is a blackish-green, totally lacking the vivid green of malachite. Glass and plastic imitations are poor. They are readily detected by their vitreous luster and usually molded appearance.

Black opal with a predominantly green play of color and an opal resembling chrysoprase could be described as nontransparent green gemstones. They are readily identified by opal's low index (1.45) and specific gravity (2.15).

Chapter XXVI

The Identification of Nontransparent Red, Orange, Yellow, and Brown Gemstones and Their Substitutes

Nontransparent gemstones and substitutes that occur in this broad range of colors include pyrite, marcasite, synthetic and natural star ruby, synthetic brown and natural black star sapphire, chrysoberyl cat's-eye, pink grossularite garnet, smithsonite, rhodonite, rhodochrosite, coral and its substitutes, amber and its substitutes, the sunstone variety of feldspar, brown tiger's-eye, yellow and brown cat's-eye quartz (both dyed other colors, as well), carnelian, sard, jasper, scapolite, thomsonite, the thulite variety of zoisite, obsidian, opal, glass and plastic. Yellow and orange jadeite may be found in rather intense colors; yellow to orangy-brown is also seen, but truly red jade is unknown.

First Test. The unknown is examined by unaided eye or a low power loupe to note characteristics and to detect any unusual or even unique properties that may be of value in eliminating some of the possibilities. Examine color nuances; luster; the presence of cleavage; luster on fracture surfaces; optical phenomena, such as asterism, chatoyancy and aventurescence; quality of polish; and inclusions. Any of the following observations may be of value:

If a star is visible, the possibilities include corundum, synthetic corundum, corundum doublets, synthetic corundum or quartz foil backs, garnet, or beryl.

Chatoyancy suggests chrysoberyl, quartz, or moonstone.

A flesh-red color suggests rhodonite, rhodochrosite, coral, conch pearl or shell.

A striped pink-and-white effect suggests coral.

An agatelike banding suggests smithsonite, rhodochrosite, or chalcedony.

A like "heft" to the hand suggests plastic, amber or an amber substitute.

Warmth to the touch suggests glass, plastic, opal, amber, or an amber substitute.

A waxy luster on a fracture surface suggests chalcedony quartz.

Second Test. If the unknown has a flat polished facet, take a normal refractive index reading. In the more likely case that it is cut *en cabochon* and has only curved surfaces, take a spot reading. Be sure that the spot is reduced to no greater than two or three scale divisions in diameter, for greatest accuracy in reading. Although the refractive index by this method is not readable to quite the accuracy of the flat-facet method, it should suffice to reduce the number of possibilities materially. If no index reading is possible, the other properties of these gemstones will prove of value in identifying the stone.

Upon completion of the refractive index determination, either by the usual method or the spot method, the only gemstones in this color grouping that may have an index above the scale are metallic pyrite and marcasite and almandite garnet. Pyrite and marcasite are both listed but, because of marcasite's tendency to decompose, only pyrite is used in "marcasite" jewelry; this terminology dates back at least two centuries. Since neither has a significant value, the use of the term marcasite is to be regarded more as custom than as an effort to misrepresent. In polished form, pyrite seems slightly whiter than the brass-yellow color of its crystals. The specific gravity is near 4.95 (4.85-5.05), the streak is greenish black, and the hardness is about 6.5.

Star garnet is nontransparent; otherwise, it fits the usual description of almandite. As a star stone, it is always cut *en cabochon;* and, since the back is usually rough, it is usually impossible to get a flat-facet refractive index reading. However, with some garnets the spot stays dark all the way to the liquid reading, whereas others give a reading close to the upper limit of the scale. The four-rayed star effect suggests garnet, because it is one of the few gemstones that exhibits a star of this kind.

Name	**R.I.**	**S.G.**	**Hard.**	**Additional**
Pyrite	opaque	5.00	6-6.5	brassy, streak
Marcasite	opaque	4.85	6-6.5	grayish
Almandite	1.81	4.05	7.5	4-ray star
Corundum	1.762-1.770	4.00	9	hexagonal zoning
Syn. corundum	1.762-1.770	4.00	9	bubbles
Chrysoberyl	1.746-1.755	3.73	8.5	silk
Grossularite	1.745	3.6	7	
Rhodonite	1.73-1.74	3.5	5.5-6.5	flesh red
Zoisite (thulite)	1.700-1.706	3.3	6-6.5	
Jadeite	1.654-1.667	3.34	6.5-7	spectrum
Smithsonite	1.62-1.85	4.30	5	acid, effervescence
Rhodochrosite	1.60-1.82	3.72	3.5-4.5	acid, effervescence
Beryl	1.57-1.58	2.70	8	
Serpentine	1.560-1.570	2.2 to 2.4	2.5-4	
Scapolite	1.550-1.572	2.68	5.5-6	
Coral	1.486-1.658	2.65	3.5	striped
Conch pearl	1.486-1.658	2.85	3.5	sheen
Shell	1.486-1.658	2.80	3.5	acid, effervescence
Quartz	1.544-1.553	2.66	7	
Amber	1.54	1.08	2-2.5	
Pressed amber	1.54	1.08	2-2.5	flow lines
Copal	1.54	1.06	2	
Chalcedony	1.535-1.539	2.60	6.5-7	waxy fracture
Feldspar	1.532-1.542	2.62	6-6.5	cleavage
Thomsonite	1.515-1.540	2.35	5-5.5	radial fibers
Obsidian	1.50	2.45	5-5.5	
Plastic	1.49 to 1.67	<2	<3	
Glass (normal)	1.48 to 1.70	2.3 to 4.5	5	molded?
Opal	1.45	2.15	5-6.5	

Synthetic and natural star rubies, synthetic sapphires and natural black sapphires all give spot readings in the 1.76-1.77 region. Imitation star rubies, made either by engraving lines on the back of transparent synthetic ruby and affixing a mirror or by using a lined metal mirror, appear opaque from the top but are obviously transparent from the side. Such imitations are easily distinguished from natural or synthetic stars by inspection. Since the introduction of the earliest Linde synthetic stars, which had only a thin layer of rutile needles making them semitransparent to translucent, both Linde and German stars have been nontransparent. The German made "Star of Freyung" is characterized by a bull's-eye effect on the flat base that is missing on most Linde stones; the circles plus a greater transparency serve to indentify it as German. In addition, the German stars show the Plato effect in contrast to the Linde stones. Both the Linde and German products show curved striae or color banding and numerous bubbles near the surface. The bubbles are seen best with a strong beam of light directed toward the side of the cabochon and the magnifier directed at a point outside of the direct surface glare of the light. Flat, ground bases such as are seen on both of the synthetics are rarely seen in natural stones, nor are natural stars often so opaque. The star in synthetics is usually much more obvious than in the natural. Synthetic brown Linde stones of early manufacture had a light color that is never seen in natural stones, which are usually black to a very dark brown. However, they are being made more nearly in the natural colors at this time. Natural stars of all colors are usually very readily identified by numerous inclusions that are larger than the minute rutile needles of the synthetics; moreover, hexagonal zoning is usually very apparent, both in color bands and inclusion patterns. Natural black stars are usually flat-topped cabochons, in contrast to the high-domed synthetic stones.

Rhodonite, which occurs in a flesh-red color with black markings, is identified by its 1.74 refractive index. The two stones of roughly comparable color, rhodochrosite and zoisite, have distinctly different refractive indices. Rhodochrosite is a carbonate and shares with most carbonates a tremendous birefringence. It is readily attacked by hydrochloric acid, with the inevitable effervescence. Its low index is approximately 1.60 and the high is just over the scale, at 1.817. Zoisite of the pink thulite variety has indices of 1.70 to 1.71. Rhodochrosite has a specific gravity of 3.6, approximately the same figure as that of rhodonite, whereas zoisite has a value of 3.30.

Figure 154

Tumbled rhodonite showing characteristic black inclusions.

Smithsonite either in an agatelike structure in yellow and white or in a solid, vivid yellow is sometimes used as a gem material. Its characteristic identification features are its very high specific gravity, at 4.30, and its effervescence to hydrochloric acid. Its high birefringence should be obvious on the refractometer, if a Polaroid plate is rotated in front of the scale while viewing the spot at a point where a reading is seen.

Jadeite is characterized by its 1.65 refractive index and by the fact that its specific gravity is almost exactly equivalent to the density of the 3.32 liquid. In addition, it has a sharp absorption line at 4370Å in the spectroscope, which is evident either by transmitted or reflected light except with dark orange and brown stones in which the portion of the spectrum below 5000Å is absorbed.

Black star beryl is actually a dark brown with a light-brown star. The refractive index is about 1.57-1.58 and its specific gravity is near 2.70. Star beryl is strongly laminated perpendicular to the c axis (optic axis). Skeletal crystals of ilmenite lie in these planes and show elongations parallel to the prism faces of hexagonal beryl, giving rise to a weak asterism.

Coral is sometimes identified by its unusual structure. So-called precious coral grows in treelike forms, each branch of which has a radial fibrous structure in cross-section. However, the key char-

Figure 155
Branchlike coral forms. That on the right shows the typical stripes seen under low magnification.

acteristic is a striped pattern seen along the length of each branch. This is often very faint and visible only under magnification, using overhead light. This structure is duplicated in no substitute. Coral is one of several gems and substitutes in this color range to effervesce strongly to hydrochloric acid, but it is easily separated from rhodochrosite by refractive index range and from conch pearl by specific gravity. Dyed calcite, which also effervesces, may be similar in color, but it is usually mottled and appears coarser. It lacks coral's structure and translucency. Occasionally, coral is partially coated with a coral-colored gluelike material to cover white spots. This is visible under magnification. It chips off readily.

Perhaps the closest resemblance to coral is seen in conch pearl. In certain directions, it exhibits shiny reflections reminiscent of the sheen of amazonite, but in a pattern resembling sheets of flame. No such effect is seen in coral. Conch pearl has a specific gravity of 2.85, in contrast to the usual 2.65 of coral. Conch shell is sometimes cut as a coral substitute; its structure is obvious in a layered pink-and-white pattern. The layers corresponding to the growth of the shell are not likely to be confused with the stripes on coral.

Wood is sometimes dyed a coral color. Its low density identifies it. Glass imitations of coral contain gas bubbles, have a vitreous fracture surface, and are inert to hydrochloric acid. Plastic is easily recognized by its light "heft."

Scapolite with a purplish red color in a translucency similar to that of average jadeite is sometimes used in jewelry. The 1.55-1.57 refractive indices and .02 birefringence at this point on the scale serve to identify it.

Greenish-yellow serpentine is used for carvings and occasionally in jewelry. In this color, the refractive index is usually 1.54 or 1.55, rather than the usual 1.56. In the spectroscope, a fairly strong absorption band is seen in the blue from about 4600 to 4700Å. A knife blade scratches it easily.

Thomsonite is unique in appearance among gems in this color range, because of its radial fibrous structure and light red, orange, and sometimes green circles at various distances outward from the center of each spherule. The refractive index is usually near 1.52 and specific gravity is 2.3 to 2.4.

Quartz and chalcedony occur in nontransparent forms in all four of the colors discussed in this section. In the crystalline-quartz type, cat's-eye is found in a natural yellow to brownish-yellow color. Tiger's-eye occurs in reddish and yellowish-brown colors. Aventurine is less common in these colors, but all three varieties are dyed various colors. Although most quartz cat's-eye is coarse, some specimens are all but indistinguishable to the eye from fine chrysoberyl. Crystalline cat's-eye or tiger's-eye quartz is certain to have the constant refractive indices of this mineral (1.544 and 1.553), whereas chrysoberyl is approximately 1.746 and 1.755. Chalcedony, in the carnelian, agate, sard, petrified wood, or other forms, is approximately 1.535 to 1.539.

Amber, another nontransparent yellow or brown stone, was described in detail in both the yellow and orange-to-brown sections of transparent stones; therefore, its identification will not be discussed further at this point. One variety not mentioned earlier, however, is the semiopaque type that resembles wood but has layers or sections of transparent amber; it is identified by its strong resinous odor when touched with the hot point. Plastics and other amber substitutes, such as the recent resins, copal, kauri gum and pressed amber, were also discussed under transparent gemstones.

The sunstone variety of feldspar is a semitransparent to semitranslucent stone that usually occurs in a colorless to white groundmass with minute inclusions of reddish flakes of hematite. In fine

Figure 156

Copper tetrahedra and modified tetrahedra in aventurine glass.

quality, it has a moonstonelike appearance, but with a reddish-yellow rather than a bluish floating light. Commonly, it appears orangy-brown with golden reflections. It has a refractive index corresponding to either albite, of the plagioclase feldspars (1.532 to 1.54 or 1.542), or to orthoclase (1.518 to 1.526).

Obsidian in both a dull-red color and in the so-called golden sheen type is seen in this color range. The latter is nearly black, but reflections from numerous inclusions impart a golden sheen. Both types are readily identified by the 1.50 refractive index, 2.45 specific gravity, warmth to the touch, and vitreous luster on fracture surfaces.

Nontransparent opal in this color range is seldom used for jewelry; however, black opal with one of these colors predominating in the play of color is cut *en cabochon* for jewelry use. Its 1.45 refractive index and 2.15 specific gravity are characteristic. The latter figure is too low for glass and too high for plastic.

The "goldstone" type of glass imitation is usually a brownish-red color. It has a multitude of tiny metallic copper tetrahedra that act as reflectors for a spectacular display of aventurescence. Gas bubbles and copper tetrahedra identify this imitation. It has a refractive index near 1.55 and specific gravity near 2.65, so just these findings could lead a novice to an aventurine quartz determination. In addition, the luster on fractures is more accurately described as greasy than as vitreous.

Chapter XXVII

The Identification of Nontransparent White, Gray, and Black Gemstones and Their Substitutes

The white, gray and black nontransparent gem materials include hematite and its substitutes (metallic); pearl (black, gray and white); cultured pearls (black, gray and white); imitation pearls; black diamond (both natural and treated); the rare melanite variety of andradite garnet (black); star sapphires (black,white and gray); synthetic star sapphire (black and white); the rare black star spinel; white grossularite garnet; jadeite (white, gray and black); jet (black); tourmaline (black); nephrite (white, "mutton fat" and black); star beryl (black); coral (black and white); moonstone and its imitations; labradorite; metallic psilomelane in chalcedony; chalcedony (black, white and gray); alabaster; the onyx marble variety of calcite; both natural and artificial glass; and plastic.

First Test. The nontransparent unknown is examined by unaided eye or a low power loupe, to detect any unique or unusual identifying characteristics or to eliminate many of the possibilities. Examine luster, nature of cleavage or fracture; luster on the breaks; optical phenomena, such as chatoyancy or asterism; quality of polish; and any other features. Any of the following characteristics may be of use in reducing the number of possibilities:

A blue sheen in reflected light suggests precious moonstone (orthoclase feldspar).

A play of color suggests opal. Since opal doublets are common, check every opal for that possibility by an examination of the girdle and back.

A blue or green iridescence in a gray gemstone suggests labradorite feldspar.

A six-rayed star suggests star sapphire or synthetic star sapphire.

Warmth to the touch (compared to the cold feel of crystalline materials) suggests a plastic, glass, or opal.

A metallic luster suggests hematite, or one of its substitutes.

A molded surface appearance suggests glass or a plastic.

A vitreous luster on a fracture surface suggests glass.

A waxy luster on a fracture surface suggests chalcedony quartz.

Crescents of white in a black stone suggests black coral.

Agatelike banding of material with alternate metallic and vitreous layers suggests psilomelane quartz.

Second Test. If the unknown has a flat polished facet, take a normal refractive index reading. In the more likely case that it is cut *en cabochon* and has only curved surfaces, take a spot reading. Be sure that the spot is reduced to no greater than two or three divisions in diameter. for greater accuracy in reading. Although the refractive index taken by this method is not readable to quite the accuracy of the flat-facet method, it should reduce the number of possibilities materially. If no index reading is possible, the other properties of these gemstones will suffice to identify the stone.

It is hard to imagine that a gemstone with such a relatively low value as that of hematite would need to have substitutes. However, there have been many substitutes for this mineral, the best known of which was sold for a number of years under the trade name of Hemetine. The apparent purpose was to avoid the cost of carving by stamping or molding the figures. The similarity of the name to hematite resulted in the ultimate abolition of the term by legal action. Hematite and its substitues are distinguished from other opaque materials by their metallic luster. Hematite has a refractive index of approximately 3.0, a specific gravity of 5.08 to 5.2, a splintery fracture, a reddish-brown streak, and a hardness of 5.5 to 6.5. The various substances used as Hemetine ranged in hardness

Name	R.I.	S.G.	Hard.	Additional
Hematite	opaque	5.20	5.5-6.5	red-brown streak, fracture
Hemetine	opaque	4.0-7.0	2.5-6	stamped impression
Diamond	2.417	3.52	10	girdle, cleavage
Andradite	1.885	3.84	6.5-7	black
Corundum	1.762-1.770	4.0	9	black star
Syn. corundum	1.762-1.770	4.0	9	white star
Grossularite	1.735	3.61	7	white
Syn. spinel	1.728	3.64	8	moonstone imitation
Spinel	1.718	3.55	8	black star
Jadeite	1.654-1.667	3.34	6.5-7	
Jet	1.66	1.32	2.5-4	black
Tourmaline	1.624-1.644	3.20	7-7.5	black
Nephrite	1.606-1.632	2.95	6-6.5	
Coral (black)	1.56-1.57	1.37	3	white crescents
Beryl	1.57-1.58	2.70	8	black star
Labradorite	1.559-1.568	2.7	6-6.5	labradorescence
Chalcedony	1.535-1.539	2.60	6.5-7	
Psilomelane	1.535-1.539	3.0	6.5-7	banded, metallic luster
Alabaster	1.52-1.53	2.3	2	
Orthoclase	1.518-1.526	2.56	6-6.5	moonstone
Imitation pearl	1.51 ±			magnification
Pearl	1.50-1.65	2.70	2.5-4	acid, effervescence
Cultured pearl	1.50-1.65	2.75	2.5-4	acid, effervescence
Mother-of-pearl	1.50-1.65	2.75	2.5-4	acid, effervescence
Coral (white)	1.486-1.658	2.65	3.5	acid, effervescence
Calcite	1.486-1.658	2.70	3	acid, effervescence
Obsidian	1.50	2.45	5-5.5	
Plastic	1.49 to 1.67	<2	<3	
Glass (normal)	1.48 to 1.70	2.3 to 4.5	5	molded?
Opal	1.450	2.15	5-6.5	play of color

from about 2.5 to 6 and in specific gravity from about 4.0 to 7.0. In its early days, powdered galena (PbS) was used as the principle ingredient; at that time the specific gravity was approximately 7.0, the hardness about 2.5, and the streak black. Later, apparently, a sintered iron oxide was used; it closely duplicated the properties of hematite, except that it lacked the splintery fracture. The streak for this type is a slightly darker brown than that of hematite. Other substitutes, such as steel and monel metal, both have metallic streaks, in contrast to hematite's reddish-brown streak. The sintered product is usually picked up by a magnet, in contrast to hematite. A simple means of detection is to examine the figure under magnification with overhead light. The grooved nature of carving contrasts sharply with the surface of a stamped or molded impression.

Black diamond, as in other colors, is distinguished by the sharpness of facet edges, the unique lathe-turned girdle surface. and often by naturals. Cleavage is often evident. Usually when a thin section is examined, the color passing through the thin portion is usually grayish. Diamond colored black by intense radiation in a cyclotron or a nuclear reactor is virtually indistinguishable from the natural; however, thin sections are usually greenish. The only clue is that it is a dense impenetrable black whereas the natural usually shows clear areas of variation in blackness. It is possible to be sure of its artificial coloring only when light can be passed through a thin edge and the 5920Å line becomes visible in the spectroscope.

The black form of andradite garnet is very rarely used as a gemstone. Its 3.84 specific gravity, as opposed to diamond's 3.52, and its somewhat lower luster distinguish it from diamond.

Natural star sapphire may be white, gray or black (although dark brown is more common). The only synthetic star in this color range is a nearly opaque white one with an exceedingly strong star. Linde is attempting to produce a black, but efforts to date have only resulted in brown ones. The growth lines in the natural stone are usually strongly evident so there is rarely any difficulty separating it from the synthetic. A nearly opaque nonasteriated white to gray material that has typical property values for corundum suggests that sintered synthetic corundum is now being made and that it may reach the gem market at any time. It has a refractive index near 1.77, a specific gravity just slightly lower than the 4.0 range of natural corundum, a dull fracture luster, and a granular appearance similar to porcelain.

Black star spinel is found on rare occasions. If the material were cut into a sphere, both four- and six-rayed stars would be seen, because the inclusions parallel octahedral face edges. Its index is a typical 1.715, but the specific gravity is lower than transparent spinel at 3.55. Black synthetic spinel triplets are made occasionally from colorless material, using a black cement. Immersion detects them.

Grossularite garnet in a white color is distinguished by its 1.725 refractive index, the only stone in that index vicinity in this color range.

White jadeite is relatively common, particularly with spots of green; in a black color, it is much more rare. White jadeite shows the 4370Å line in the spectroscope, and, whether white or black, its specific gravity (near 3.32) is characteristic. The only other black gemstone with a comparable refractive index is jet (1.66), and it is easily distinguished from jadeite by its very low specific gravity (1.35). A black plastic could imitate jet effectively, but the acrid plastic odor emitted when touched by a hot point would detect it. Jet has a coallike odor.

Nephrite jade occurs both in white to off-white (so-called mutton fat) and black form. The only materials in its refractive index range are tourmaline, glass and plastic. Schorl, the black variety of tourmaline, has a full .03 birefringence, in contrast to a single vague reading for nephrite (near 1.61). Nephrite is usually less than 3.0 in specific gravity, compared to 3.2 for schorl. Black nephrite takes a high polish, and its high luster and extreme toughness make it perhaps the best of the opaque black stones for gem use. Black tourmaline is more brittle, so it is seldom used. Black nephrite lacks any serious drawback but black onyx is far better known, perhaps because it is both harder and more common.

Dark-brown to nearly black star beryl is seen rarely. It has a poorly developed yellow-brown star reminiscent of black star sapphire. The low refractive index and specific gravity identify it readily. Star beryl is strongly laminated in appearance perpendicular to the optic axis.

White coral at times is a popular gem material, particularly for inexpensive summer jewelry. Its properties are comparable to those of the pink variety — approximately those of calcite: refractive indices of 1.486 and 1.658; specific gravity, about 2.65; and a typical coral structure. Conch shell, used to imitate white coral, has the usual shell-layered structure.

Black coral differs materially, in that the material secreted by the tiny animal colonies is not calcium carbonate but a horny material; as a result, it does not effervesce under a drop of hydrochloric acid. It has indices of 1.56 and 1.57 (birefringence .01) and its specific gravity is 1.37. It is characterized by white crescents in the cross sections of the branchlike forms.

White or black calcite in the form of limestone marble or onyx marble is often used for carvings and other ornamental objects. Alabaster, too, has similar uses. Calcite is identified by its strong effervescence to hydrochloric acid and its strong birefringence by the spot method (refractive indices, 1.486 and 1.658). Alabaster is notable for its low hardness of 2- and its low index (1.52-1.53).

Quartz in a milky form is quite common, having the usual 1.544 and 1.553 refractive indices to set it apart. It resembles moonstone, but without the "floating" light effect. Chalcedony quartz occurs in white, gray and black colors. Most so-called black onyx is actually gray agate that has been dyed black. Gray agate is seldom used except to be dyed various colors. Fire agate is a translucent to almost semitransparent white agate in which light interference causes iridescent color effects. The 1.535 to 1.539 refractive index, plus a specific gravity near 2.60, are characteristic. A gem material popular in tumbled stone jewelry and in cabochons is that frequently sold as psilomelane. It is actually mainly chalcedony, with alternate thin agatelike layers of psilomelane, a manganese mineral with a metallic luster. Refractive indices are those for chalcedony but the specific gravity is usually near 3.0 to 3.1.

Orthoclase moonstone is also a relatively common gem material. No other natural stone has a comparable adularescence, although there are imitations with similar effects. Synthetic white spinel is an excellent imitation of moonstone, as are some plastics and glass. Refractive index or heft to the hand is sufficient to distinguish synthetic spinel from moonstone. The very low specific gravity and molded nature of plastic gives its identity away. The polariscope proves both synthetic spinel and plastic to be singly refractive, in contrast to moonstone. Some moonstone has properties corresponding to those of albite of the plagioclase group of feldspars. This means indices up to almost 1.54 and specific gravities to about 2.6. Labradorite, a gray feldspar with a broad color effect caused by light interference, is occasionally used for carvings and cabochons. It is identified by the strong parallel banding caused by repeated twinning, the numerous black rodlike inclusions that cause the gray color, evidence of cleavage, and its 1.559 and 1.568 indices.

Black obsidian is a plentiful substance, but it is not an important gem material. The type of dark-brown or black obsidian with inclusions that give rise to shiny reflections is often called golden-sheen obsidian; it is used for carvings and cabochons. Its single refraction and refractive index of about 1.50 identify it. "Snowflake" obsidian is black with white areas of the cristobolite form of quartz.

White and black opal are perhaps the most important gemstones in the white, gray and black nontransparent category. Black opal with a vivid play of color in red, violet, yellow and other hues is particularly prized. About the only imitation of either stone is the opal doublet. Glass with inclusions or backing of metal foil to create an iridescent effect is easily recognized as such by eye. The opal doublet is easily detected by careful inspection of the girdle area. However, if the stone is mounted, a bezel observed under magnification may show a chip in one layer, or a separation in the joining area of the two layers.

The identification of pearls, cultured pearls and imitations is discussed in Chapter XII. Methods for distinguishing between dyed and naturally colored black pearls are included in that chapter.

Mother-of-pearl is recognized by the fact that the pearly luster is confined to two opposite areas on any polished piece; polish marks are visible in the areas not having the pearly luster. Some white to rosé mother-of-pearl is dyed black, giving it a superficial resemblance to cat's-eye or black star sapphire. The refractive indices of mother-of-pearl are in the aragonite range (1.53 and

1.685), and the material effervesces strongly under a drop of hydrochloric acid. Both natural and cultured pearls give spot readings showing strong birefringence when a Polaroid plate is rotated before the eyepiece; the high and low limits seem to correspond closely to the expected results for aragonite. Imitations show no birefringence. The relatively thick transparent overcoat on imitations is seen easily under magnification and it often reveals bubbles. The imitation usually is smooth to the cutting edge of the tooth, and often peeling is in evidence at the drill hole. Often. glassy fractures may be seen at the drill holes.

Appendix

COLOR TABLE

Purple and Violet Gemstones and Their Substitutes

Transparent

Almandite garnet
Beryl (morganite)
Chrysoberyl (alexandrite)
Corundum (sapphire)
Diamond
Glass
Plastics
Pyrope garnet
Quartz (amethyst)
Rhodolite garnet
Spinel
Spodumene (kunzite)
Synthetic corundum
Synthetic spinel
Topaz
Tourmaline
Zircon
Doublets

Gems infrequently encountered in the jewelry trade:

Andalusite
Apatite
Axinite
Fluorite
Iolite
Scapolite
Taaffeite

Nontransparent

Almandite garnet
Corundum (star sapphire)
Jadeite
Quartz (chalcedonic)
Stichtite
Thomsonite

Blue Gemstones and Their Substitutes

Transparent

Beryl (aquamarine)
Corundum (sapphire)
Diamond
Glass
Iolite
Plastics
Quartz (dyed)
Chalcedony (dyed and natural)
Opal
Spinel
Synthetic corundum
Synthetic rutile
Synthetic spinel
Topaz
Tourmaline
Zircon
Doublets
Triplets
Foil backs

Gems infrequently encountered in the jewelry trade:

Apatite
Benitoite
Euclase
Fluorite
Kornerupine
Kyanite
Lazulite
Sillimanite

Nontransparent

Azurite
Chalcedonic quartz (chrysocolla quartz and dyed chalcedony)
Corundum (star sapphire)
Glass
Jadeite
Labradorite feldspar
Lazurite (lapis lazuli)
Opal (black opal)
Plastics
Quartz (cat's-eye quartz)
Sintered synthetic spinel
Synthetic corundum
Turquoise
Doublets
Foil backs

Gems infrequently encountered in the jewelry trade:

Diopside
Dumortierite
Lazulite
Odontolite
Smithsonite
Sodalite

Green Gemstones and Their Substitutes

Transparent

Andradite garnet (demantoid)
Beryl (emerald)
Chrysoberyl (including cat's-eye and alexandrite)
Corundum (green sapphire)
Diamond
Glass
Peridot
Plastics
Chalcedonic quartz (chrysoprase)
Quartz
Spinel
Synthetic corundum
Synthetic emerald
Synthetic rutile
Synthetic spinel
Topaz
Tourmaline
Zircon
Doublets
Triplets

Gems infrequently encountered in the jewelry trade:

Andalusite
Apatite
Brazilianite
Datolite
Diopside
Dioptase
Ekanite
Enstatite
Epidote
Euclase
Fluorite
Gahnite
Gahnospinel
Jadeite
Kornerupine
Kyanite
Moldavite
Obsidian
Sphalerite
Sphene
Spodumene
Willemite

Nontransparent

Agalmatolite
Beryl
Calcite (dyed onyx marble)
Chalcedonic quartz (chrysoprase or bloodstone and dyed chalcedony)
Chlorastrolite
Chrysoberyl (cat's-eye)
Corundum
Glass
Grossularite garnet
Idocrase
Jadeite jade
Labradorite feldspar
Malachite
Microcline feldspar (amazonite)
Nephrite jade
Opal (black opal)
Prehnite
Pseudophite
Quartz (aventurine)
Saussurite
Serpentine
Sillimanite
Smithsonite
Steatite
Synthetic emerald
Tourmaline
Turquoise
Variscite
Verdite

Yellow Gemstones and Their Substitutes

Transparent

- Amber
- Beryl
- Chrysoberyl
- Corundum
- Diamond
- Glass
- Grossularite garnet (hessonite)
- Opal
- Peridot
- Plastics
- Quartz (citrine)
- Spessartite garnet
- Spodumene
- Synthetic corundum
- Synthetic rutile
- Synthetic spinel
- Topaz
- Tourmaline
- Zircon
- Doublets
- Triplets
- Foil backs

Gems infrequently encountered in the jewelry trade:

- Apatite
- Axinite
- Beryllonite
- Brazilianite
- Cassiterite
- Copal
- Danburite
- Fluorite
- Labradorite feldspar
- Orthoclase feldspar
- Phenakite
- Scapolite
- Smithsonite
- Sphene
- Spinel
- Stibiotantalite

Nontransparent

- Amber
- Chalcedonic quartz
- Chrysoberyl (cat's-eye)
- Jadeite jade
- Plastics
- Smithsonite

Brown and Orange Gemstones and Their Substitutes

Transparent

- Amber and pressed amber
- Beryl
- Chrysoberyl
- Copal (and other natural resins)
- Corundum
- Diamond
- Doublets
- Glass
- Grossularite garnet (hessonite)
- Opal (fire opal)
- Plastics
- Quartz
  - Chalcedony
- Sinhalite
- Spinel
- Synthetic corundum
- Synthetic rutile
- Synthetic spinel
- Topaz
- Tourmaline
- Triplets
- Zircon

Gems infrequently encountered in the jewelry trade:

- Anatase
- Andalusite
- Axinite
- Cassiterite
- Copal
- Enstatite
- Idocrase
- Kornerupine
- Obsidian
- Peridot
- Scheelite
- Spessartite garnet
- Sphalerite
- Sphene
- Staurolite
- Willemite

Nontransparent

- Amber
- Chalcedonic quartz
- Chrysoberyl (cat's-eye)
- Jadeite jade
- Opal
- Plastics
- Quartz tiger's-eye
- Smithsonite
- Sunstone
- Synthetic corundum

Red and Pink Gemstones and Their Substitutes

Transparent

- Almandite garnet
- Beryl (morganite)
- Chrysoberyl (alexandrite)
- Corundum (ruby and pink sapphire)
- Diamond
- Glass
- Opal (fire opal)
- Plastics
- Pyrope garnet
- Quartz (rose quartz)
- Chalcedony (carnelian and sard)
- Rhodolite garnet
- Spinel
- Spodumene (kunzite)
- Synthetic corundum
- Synthetic rutile
- Synthetic spinel
- Topaz
- Tourmaline (rubellite and Bordeaux tourmaline)
- Zircon
- Doublets
- Triplets
- Foil backs

Gems infrequently encountered in the jewelry trade:

- Amber
- Andalusite
- Apatite
- Apophyllite
- Cassiterite
- Danburite
- Epidote
- Fluorite
- Painite
- Phenakite
- Pollucite
- Rhodochrosite
- Rutile
- Scapolite
- Spessartite
- Sphalerite
- Zincite

Nontransparent

- Almandite garnet (star garnet)
- Chalcedonic quartz (sard, sardonyx, and carnelian)
- Conch pearl
- Coral
- Corundum (star ruby)
- Glass
- Grossularite
- Jadeite
- Plastics
- Quartz (cat's-eye quartz)
- Rhodochrosite
- Rhodonite
- Scapolite
- Stichtite
- Synthetic corundum
- Thomsonite
- Zoisite (thulite)
- Foil backs

Colorless Gemstones and Their Substitutes

Transparent

- Beryl
- Corundum (white sapphire)
- Diamond
- Glass
- Opal
- Orthoclase feldspar (moonstone)
- Plastics
- Quartz (rock crystal)
- Spinel
- Strontium titanate
- Synthetic corundum
- Synthetic rutile
- Synthetic spinel
- Topaz
- Tourmaline
- Zircon (jargoon)

Gems and their substitutes infrequently encountered in the jewelry trade:

- Amblygonite
- Apatite
- Augelite
- Benitoite
- Beryllonite
- Brazilianite
- Danburite
- Euclase
- Fluorite
- Hambergite
- Jadeite
- Labradorite
- Leucite
- Petalite
- Phenakite
- Pollucite
- Rhodizite
- Scapolite
- Scheelite
- Spodumene
- Doublets

White Gemstones and Their Substitutes

Nontransparent

- Alabaster
- Chalcedonic quartz (chalcedony moonstone)
- Coral
- Corundum
- Glass
- Jadeite jade
- Nephrite jade
- Onyx marble
- Opal
- Opal doublets
- Orthoclase feldspar (moonstone)
- Plastics
- Synthetic corundum
- Synthetic spinel

Black Gemstones and Their Substitutes

Nontransparent

- Andradite garnet (melanite)
- Black coral
- Chalcedonic quartz (black onyx)
- Corundum (star sapphire)
- Diamond
- Glass
- Hematite
- Hemetine
- Jadeite jade
- Jet
- Nephrite jade
- Obsidian
- Opal
- Opal doublets
- Plastics
- Psilomelane
- Tourmaline

Gray Gemstones and Their Substitutes

Nontransparent

- Chalcedonic quartz (agate)
- Corundum (star sapphire)
- Hematite
- Hemetine
- Jadeite jade
- Labradorite feldspar
- Nephrite jade
- Sintered synthetic corundum

TABLE OF PERFECT AND DISTINCT CLEAVAGE AND PARTING

One Direction

EUCLASE	Perfect	SILLIMANITE	Perfect
EPIDOTE	Perfect	TOPAZ	Perfect
IOLITE	Distinct	ZOISITE	Perfect

Two Directions

BERYLLONITE	One perfect, one nearly perfect—90° between directions.
BRAZILIANITE	Perfect.
DIOPSIDE	Perfect—92½° between directions.
ENSTATITE	Perfect—88° between directions.
FELDSPAR (Orthoclase, microcline, albite-oligoclase, labradorite.)	One perfect, one nearly so—90° to 86° between directions.
JADEITE	Perfect—93° between directions, but usually concealed by fine aggregate structure.
KORNERUPINE	Perfect.
KYANITE	One perfect, one less so—74° between directions.
NEPHRITE	Perfect—56° and 124° between directions, but concealed by aggregate structure.
RHODONITE	Perfect—92½° between directions—tough when massive.
SCAPOLITE	Perfect—90° between directions.
SPHENE	Distinct—66½° between directions.
SPODUMENE	Perfect—93° between directions—one direction of easy parting sometimes prominent.

Three Directions

CALCITE	Perfect—concealed in onyx marble by fine grain.
DIOPTASE	Perfect.
SMITHSONITE	Perfect—concealed by fine grain.

Four Directions

CORUNDUM	Distinct parting
DIAMOND	Perfect
FLUORITE	Perfect

Six Directions

SODALITE	Fairly Distinct
SPHALERITE	Perfect

PLEOCHROISM TABLE

The symbols S, D, W, and VW signify strong, distinct, weak, and very weak pleochroism. Only two colors are given for biaxial gemstones when little color difference is detectable between two of the three directions. Colors may vary from those described, depending on hue and depth of color.

Purple or violet gemstones

Corundum (sapphire) (S)	Violet and orange
Tourmaline (S)	Purple and light purple
Andalusite (S)	Brownish-green and dark red to purple
Spodumene (kunzite) (S)	Violet to purple and colorless to pink
Beryl (D-S)	Violet and colorless
Chrysoberyl (alexandrite) (S)	Dark red-purple, orange, and dark green (trichroic)
Topaz (D-S)	Light to very light purple

Blue gemstones

Beryl (W-D)	Light blue and darker blue
Corundum (S)	Dark violetish-blue and light greenish-blue
Topaz (W-D)	Colorless and light blue
Tourmaline (S)	Dark blue and light blue
Zircon (S)	Medium blue and colorless to gray
Apatite (S)	Blue and yellow
Benitoite (S)	Colorless and dark blue
Iolite (S)	Colorless to yellow, blue, and dark blue-violet (trichroic)

Green gemstones

Beryl (emerald) (S)	Green and blue-green
Corundum (sapphire) (S)	Green and yellow-green
Tourmaline (S)	Blue-green to dark brownish-green and yellow-green
Zircon (W)	Brownish-green and green
Topaz (D)	Blue-green and light green
Sphene (D)	Brownish-green and blue-green
Andalusite (S)	Brownish-green and dark red
Chrysoberyl (alexandrite) (S)	Dark red, orange, and green (trichroic)
Peridot (W)	Yellow-green and green

Yellow gemstones

Beryl (W)	Light greenish-yellow and light blue-green
Chrysoberyl (D)	Colorless, very light yellow, and greenish-yellow (trichroic)
Corundum (W)	Yellow and light yellow
Danburite (W)	Very light yellow and light yellow
Phenakite (D)	Colorless and orange-yellow
Quartz (citrine) (VW)	Light yellow and very light yellow
Spodumene (D)	Light yellow and very light yellow
Topaz (D)	Brownish-yellow, yellow, and orange-yellow (trichroic)
Tourmaline (D)	Light yellow and dark yellow
Zircon (W)	Yellow-brown and yellow

Brown and orange gemstones

Axinite (S)	Violet, yellow-brown, and green (trichroic)
Corundum (S)	Yellow-brown to orange and colorless
Quartz (W)	Brown and reddish-brown
Topaz (D)	Yellow-brown and brown
Tourmaline (S)	Yellowish-brown—dark greenish-brown
Zircon (W-D)	Brownish-yellow and purplish-brown

Pink and red gemstones

Andalusite (S)	Dark red and brownish-green
Beryl (morganite) (D)	Light red and red-violet
Chrysoberyl (alexandrite) (S)	Dark red, orange, and green (trichroic)
Corundum (ruby) (S)	Violetish-red and orangy-red
Synthetic corundum (S)	Violetish-red and orangy-red
Spodumene (kunzite) (S)	Light red to purple and colorless
Topaz (D to S)	Light red and yellow
Tourmaline (S)	Dark red and light red
Zircon (D)	Reddish-purple and reddish-brown

Refractive Index Table

Rutile & Syn	2.616		2.903
Anatase	2.493		2.554
Diamond		2.417	
Strontium titanate		2.409	
Stibiotantalite	2.37		2.45
Sphalerite		2.37	
Zincite	2.013		2.029
Cassiterite	1.997		2.093
Zircon (high)	1.925		1.984
Scheelite	1.918		1.934
Sphene	1.900 (±.018)		2.034 (±.020)
Zircon (medium)	1.875 (±.045)		1.905 (±.075)
Andradite garnet		1.875 (±.020)	
Zircon (low)	1.810 (±.020)		1.815 (±.020)
Spessartite garnet		1.81 (±.010)	
Almandite garnet		1.80 (±.030)	
Gahnite		1.80	
Painite	1.787		1.816
Corundum	1.762 (—.003, +.007)		1.770 (—.003, +.008)
Synthetic corundum	1.762		1.770
Rhodolite garnet		1.76 (±.010)	
Benitoite	1.757		1.804
Gahnospinel		1.76 (±.02)	
Pyrope garnet		1.746 (—.026, +.010)	
Chrysoberyl	1.746 (±.004)		1.755 (±.005)
Staurolite	1.736		1.746
Grossularite garnet		1.735 (±.015)	
Azurite	1.73 (±.010)		1.84 (±.010)
Rhodonite	1.73		1.74
Epidote	1.729 (—.015, +.006)		1.768 (—.035, +.012)
Synthetic Spinel		1.73 (±.01)	
Spinel		1.718 (—.006, +.044)	
Taafeite	1.719		1.723
Kyanite	1.716 (±.004)		1.731 (±.004)
Idocrase	1.713 (±.012)		1.718 (±.014)
Zoisite	1.700		1.706
Willemite	1.69		1.72
Rhodizite		1.69	
Dumortierite	1.678		1.689
Axinite	1.678		1.688
Diopside	1.675 (—.010, +.027)		1.701 (—.007, +.029)
Sinhalite	1.668 (±.003)		1.707 (±.003)
Kornerupine	1.667 (±.002)		1.680 (±.003)
Malachite	1.66		1.91
Spodumene	1.660 (±.005)		1.676 (±.005)
Sillimanite	1.659		1.68
Jet		1.66 (±.020)	
Enstatite	1.658 (±.005)		1.668 (±.005)
Dioptase	1.655 (±.011)		1.708 (±.012)
Jadeite	1.654		1.667
Euclase	1.654 (±.004)		1.673 (±.004)
Phenakite	1.654 (—.003, +.017)		1.670 (—.004, +.026)
Peridot	1.654 (±.020)		1.690 (±.020)
Apatite	1.642 (.—012, +.003)		1.646 (—.014, +.005)

Refractive Index Table

Andalusite	1.634(±.006)	1.643(±.004)
Danburite	1.630(±.003)	1.636(±.003)
Datolite	1.626	1.670
Tourmaline	1.624(±.005)	1.644(±.006)
Smithsonite	1.621	1.849
Topaz	1.619(±.010)	1.627(±.010)
Prehnite	1.615	1.646
Turquoise	1.61	1.65
Lazulite	1.612	1.643
Amblygonite	1.612	1.636
Bakelite	1.61(±.06)	
Nephrite	1.606	1.632
Brazilianite	1.602	1.621
Odontolite	1.60(±.03)	1.61(±.03)
Ekanite	1.597	
Rhodochrosite	1.597	1.817
Verdite	1.580	
Beryl	1.577(±.016)	1.583(±.017)
Synthetic emerald (Linde)	1.575	1.581
Augelite	1.574	1.588
Pseudophite	1.57	1.58
Synthetic emerald (Chatman)	1.561	1.565
Variscite	1.56	1.59
Coral (black)	1.56	1.57
Labradorite feldspar	1.559	1.568
Hambergite	1.555	1.625
Beryllonite	1.552	1.562
Agalmatolite	1.55	1.66
Scapolite	1.55	1.572
Quartz	1.544(±.00)	1.553(±.00)
Iolite	1.542(—.010, +.002)	1.551(—.011, +.045)
Steatite	1.54	1.590
Amber	1.540	
Chalcedony quartz	1.535	1.539
Apophyllite	1.535	1.537
Albite-oligoclase	1.532(±.007)	1.542(±.006)
Pollucite	1.525	
Microcline	1.522	1.530
Orthoclase	1.518	1.526
Thomsonite	1.515	1.540
Stichtite	1.516	1.512
Leucite	1.508	
Petalite	1.502	1.518
Lazurite (lapis-lazuli)	1.500	
Obsidian	1.500	
Lucite	1.495(±.005)	
Serpentine	1.56(—.07)	1.570(—.07)
Calcite	1.486	1.658
Coral	1.486	1.658
Sodalite	1.483(±.003)	
Moldavite	1.48	
Opal	1.45(—.080, +.020)	
Fluorite	1.434	
Glass (normal)	1.48 - 1.70	
(extreme)	1.44 - 1.77	

TABLE OF DISPERSION

The following figures represent the difference in the gem's refractive index for red light and blue-violet light.

Fluorite	.007	Idocrase	.019
Silica glass	.010	PERIDOT	.020
Beryllonite	.010	SPINEL	.020
Kyanite	.011	Dioptase	.022
ORTHOCLASE FELDSPAR	.012	ALMANDITE GARNET	.024
QUARTZ	.013	Rhodolite Garnet	.026
BERYL	.014	PYROPE GARNET	.027
TOPAZ	.014	Spessartite Garnet	.027
Phenakite	.015	GROSSULARITE GARNET	.028
CHRYSOBERYL	.015	Epidote	.030
Fibrolite	.015	ZIRCON	.038
Euclase	.016	Benitoite	.044
Danburite	.016	DIAMOND	.044
Datolite	.016	Sphene	.051
Scapolite	.017	ANDRADITE GARNET	.057
TOURMALINE	.017	Cassiterite	.071
SPODUMENE	.017	Sphalerite	.156
CORUNDUM	.018	Strontium titanate	.198
Kornerupine	.019	Synthetic rutile	.330

TABLE OF BIREFRINGENCE OF GEMSTONES

Apatite	.004	Kyanite	.016
BERYL	.006	Phenakite	.016
CORUNDUM	.008	Euclase	.019
TOPAZ	.008	TOURMALINE	.020
Andalusite	.009	Sillimanite	.021
CHRYSOBERYL	.009	PERIDOT	.038
QUARTZ	.009	ZIRCON	.059
Beryllonite	.010	Calcite	.172
SPODUMENE	.015	SYNTHETIC RUTILE	.287

Specific Gravity Table

Stibiotantalite	7.50(±.30)
Cassiterite	6.95(±.08)
Scheelite	6.12
Zincite	5.70
Hematite	5.20(±.08)
Strontium titanate	5.13(±.02)
Pyrite	5.00(±.10)
Marcasite	4.85(±.05)
Zircon	
(high)	4.70(±.03)
(medium)	4.32(±.25)
Gahnite	4.55
Smithsonite	4.30(±.10)
Rutile & Syn.	4.26(±.02)
Spessartite	4.15(±.03)
Almandite	4.05(±.12)
Sphalerite	4.05(±.02)
Painite	4.01
Gahnospinel	4.01(±.40)
Zircon (low)	4.00(±.07)
Corundum & Syn.	4.00(±.03)
Malachite	3.95(—.70,+.15)
Anatase	3.90
Andradite	3.84(±.03)
Rhodolite	3.84(±.10)
Azurite	3.80(—.50,+.07)
Pyrope	3.78(—.16,+.09)
Chrysoberyl	3.73(±.02)
Staurolite	3.71(±.06)
Rhodochrosite	3.70
Syn. spinel	3.65(—.12,+.02)
Benitoite	3.64(±.03)
Kyanite	3.62(±.06)
Grossularite	3.61(±.14)
Spinel	3.60(—.03,+.30)
Taaffeite	3.61
Topaz	3.53(±.04)
Diamond	3.52(±.01)
Sphene	3.52(±.02)
Sinhalite	3.48
Rhodonite	3.50(±.20)
Idocrase	3.40(±.10)
Epidote	3.40(±.08)
Rhodizite	3.40
Peridot	3.34(—.03,+.14)
Jadeite	3.34(±.04)
Zoisite	3.30(±.10)
Dioptase	3.30(±.05)
Kornerupine	3.30(±.05)
Saussurite	3.30
Dumortierite	3.30
Diopside	3.29(±.03)
Axinite	3.29(—.02)
Ekanite	3.28
Enstatite	3.25(±.02)
Sillimanite	3.25(±.02)
Chlorastrolite	3.30
Fluorite	3.18(±.01)
Apatite	3.19(±.02)
Spodumene	3.19(±.03)
Andalusite	3.17(±.04)
Euclase	3.10(±.01)
Odontolite	3.10
Lazulite	3.09(±.05)
Tourmaline	3.06(—.05,+.15)
Amblygonite	3.02
Danburite	3.00(±.01)
Psilomelane	3.0
Nephrite	2.95(±.05)
Phenakite	2.95(±.01)
Datolite	2.95
Brazilianite	2.94
Pollucite	2.92
Verdite	2.90
Prehnite	2.88(±.06)
Beryllonite	2.85(±.02)
Conch Pearl	2.85
Agamatolite	2.80
Turquoise	2.76(—45,+.08)
Steatite	2.75
Lapis-lazuli	2.75(±.25)
Beryl	2.72(—.05,+.12)
Pearl	2.70(—.02,+.15)
Labradorite	2.70(±.05)
Augelite	2.70
Pseudophite	2.70
Calcite	2.70
Scapolite	2.68(±.06)
Quartz	2.66(±.01)
Syn. emerald	
(Linde)	2.68(±.03)
(Chatham)	2.66(±.01)
Oligoclase	2.65(±.02)
Coral	2.65(±.05)
Iolite	2.63(±.05)
Chalcedony	2.60(±.05)
Serpentine	2.57(±.06)
Orthoclase	2.56(±.01)
Microcline	2.56(±.01)
Variscite	2.50(±.08)
Leucite	2.50
Obsidian	2.45(±.10)
Moldavite	2.40(±.04)
Petalite	2.40
Apophyllite	2.40(±.10)
Alabaster	2.30
Thomsonite	2.35(±.05)
Hambergite	2.35

Glass	2.3 to 4.5	Coral (black) .	1.37
Sodalite . . .	2.24(±.05)	Jet	1.32(±.02)
Chrysocolla .	2.20(±.10)	Plastics . . .	1.30(±.25)
Stichtite . .	2.18(±.02)	Amber . . .	1.08(±.02)
Opal	2.15(—.17, +.07)		

Hardness Table

Diamond	10
Silicon carbide	9¼
Corundum & Syn.	9
Chrysoberyl	8½
Spinel & Syn.	8
Painite	8
Topaz	8
Taaffeite	8
Rhodizite	8
Beryl & syn. emerald	7½-8
Phenakite	7½-8
Zircon	7½
Almandite garnet	7½
Hambergite	7½
Euclase	7½
Gahnite	7½
Gahnospinel	7½
Rhodolite garnet	7-7½
Pyrope garnet	7-7½
Spessartite garnet	7-7½
Tourmaline	7-7½
Andalusite	7-7½
Iolite	7-7½
Staurolite	7-7½
Grossularite garnet	7
Quartz	7
Danburite	7
Dumortierite	7
Chalcedony	6½-7
Peridot	6½-7
Jadeite	6½-7
Andradite garnet	6½-7
Axinite	6½-7
Saussurite	6½-7
Idocrase	6½
Scapolite	6½
Kornerupine	6½
Pollucite	6½
Spodumene	6-7
Sinhalite	6-7
Epidote	6-7
Sillimanite	6-7
Cassiterite	6-7
Zoisite	6-7
Rutile & Syn.	6-6½
Microcline	6-6½
Orthoclase	6-6½
Nephrite	6-6½
Pyrite	6-6½
Benitoite	6-6½
Marcasite	6-6½
Prehnite	6-6½
Labradorite	6
Amblygonite	6
Leucite	6
Petalite	6
Hematite	5½-6½
Rhodonite	5½-6½
Beryllonite	5½-6
Anatase	5½-6
Brazilianite	5½
Enstatite	5½
Willemite	5½
Moldavite	5½
Thomsonite	5½
Opal	5-6½
Diopside	5-6
Glass	5-6
Strontium titanate	5-6
Lazulite	5-6
Lapis-lazuli	5-6
Turquoise	5-6
Sodalite	5-6
Chlorastrolite	5-6
Sphene	5-5½
Obsidian	5-5½
Datolite	5-5½
Bowenite (serpentine)	5-5½
Apatite	5
Scheelite	5
Dioptase	5
Smithsonite	5
Odontolite	5
Stibiotantalite	5
Apophyllite	4½-5
Zincite	4½
Kyanite	4-7
Variscite	4-5
Augelite	4
Fluorite	4
Rhodochrosite	3½-4½
Malachite	3½-4
Azurite	3½-4
Sphalerite	3½-4
Coral	3½
Conch pearl	3½
Calcite	3
Verdite	3
Black coral	3
Hemetine	2½-6
Pearl	2½-4½
Jet	2½-4
Pseudophite	2½
Agalmatolite	2½
Serpentine	2-4
Amber	2-2½
Copal	2
Alabaster	2
Stichtite	1½-2
Steatite (soapstone)	1-1½

Short Glossary of Gemological Terms

Absorption spectrum. The dark lines or gaps produced in a continuous spectrum by absorption of certain wave lengths by certain materials.

Amorphous. Without form. Material that has no regular arrangement of atoms, hence no crystal structure.

Anisotropic. Possessing the property of double refraction. See Chapter VI.

Asterism. A term applied to the display of a rayed figure (star) by a gemstone when cut en cabochon.

Atom. The smallest portion of an element which retains the properties of that element.

Atomic weight. The weight of an atom of an element compared to the arbitrary figure, 16 assigned to an atom of oxygen.

Biaxial. Possessing two optic axes—two axes of single refraction in a doubly refractive substance. Gems in the orthorhomic, monoclinic and triclinic crystal systems are biaxial. See Chapter VI.

Birefringence. The strength of double refraction measured by taking the difference between the high and low indices of a doubly refractive stone. See Chapter VI.

Boule. The rough form of synthetic corundum and spinel. Pear or carrot shaped.

Brilliant. A gem cut in the brilliant form (the common round diamond cut), with the table and 32 facets on the crown, and 24 facets plus the culet on the pavilion.

Cabochon. A facetless cutting style that produces convex surfaces.

Carat. Unit of weight equal to 200 milligrams.

Chatoyancy. Optical phenomenon, displayed by certain gems, that produces a thin bright line across a stone cut en cabochon. Cat's-eye effect.

Conchoidal. Type of fracture commonly seen in gems and glass. Break resembles a clam-shell surface. See page 9.

Critical angle. Largest angle measured from the normal at which light can escape from an optically dense substance and the smallest angle to the normal at which light is totally reflected within the dense substance. See Chapter V.

Cryptocrystalline. Having crystals so small that individual crystals cannot be resolved by an ordinary microscope, but detectable by effect on polarized light.

Crystal system. One of the six groups of crystal patterns in which minerals and other crystalline solids occur.

Crystal. Material with regular arrangement of atoms bounded by natural plane surfaces.

Cubic. See isometric.

Density. Mass per unit volume. See Chapter IV.

Diamondscope. Trademark name for a binocular microscope mounted on a patented dark-field illuminator base. See Chapter VII.

Dichroism. Unequal absorption of the two portions of a doubly refracted beam of light, producing two colors when observed through a dichroscope.

Dichroscope. A small instrument for gem testing that is used to detect pleochroism. See page 52.

Dispersion. The separation of white light into its component colors.

Double refraction. The property of separating a single light ray into two. See Chapter II.

Doublet. An imitation gem composed of two pieces of gem material or one of gem material and a second of glass cemented together.

Doubling of the opposite facets. Facet edges, scratches, or other objects seen as double images when viewed through a doubly refractive gem.

Emerald filter. A color filter through which imitations appear green, and emerald, synthetic emerald, and some other genuine gems have a reddish color. See Chapter IX.

Extinction. Position of darkness in a transparent anisotropic gem when examined in crossed polarized light.

Fire. See dispersion.

Fluorescence. The emission of visible light by a gem when subjected to ultra-violet or X-radiation.

Fracture. A break other than in a cleavage direction. Usually shell-like in gems. See Chapter III.

Gemolite. Trade-mark name for a binocular microscope mounted on a patented illuminator base. See Chapter VII.

Habit. The crystal form in which a mineral most often occurs; i.e., habit of diamond is the octahedron.

Hardness. Resistance a material offers to scratching or abrasion. See Chapter III.

Hardness points or pencils. Points made from gem materials for hardness determination. Hardnesses of 9, 8½, 8, 7, 6½, 6 are common, with some sets including 10, 7½, 5. See Chapter III.

Hexagonal. A crystal system (three equal axes at 60 degrees, a fourth perpendicular to the other three and unequal in length). Examples: quartz, corundum, beryl, and tourmaline.

Imperfection. Any surface or internal flaw or inclusion in a gem.

Inclusion. Internal imperfection other than fracture or cleavage in a gem.

Inorganic. Any substance not produced through the agency of living organisms.

Interference. Effect produced of two or more light waves traveling the same path after traveling different distances. If they are "in phase," they will reinforce each other (intensify the color). If they are out of phase, they will destroy each other. Interference of white light results in destruction of certain wave lengths and reinforcement of others; producing such effects as the play of color in opal.

Iridescence. Light interference effect in thin films of gas or liquid causing rainbow effects.

Isometric. Crystal system of highest symmetry with three equal crystallographic axes at right angles. Gems which crystallize in the isometric system are diamond, spinel, and the garnet group.

Liquid inclusion. Space within a substance filled or partially filled with a liquid. See Chapter VIII.

Luster. The appearance of a gem. More specifically, the quality and quantity of light reflected by a gem. Luster usually refers to the appearance of the surface.

Metamict. A condition resulting from the breakdown of the crystal structure of a mineral caused by radioactivity. In zircon, the radioactivity of uranium or thorium impurities slowly destroys the crystal lattice leaving a nearly amorphous state. In ekanite, destruction of crystal structure is complete.

Methylene iodide. An organic liquid used in gem testing. R. I. 1.74, S.G. 3.32.

Mineral. A natural inorganic material with a characteristic composition and usually possessing a crystal structure.

Mohs' Scale. An arbitrary scale of hardness with numbers from one to ten assigned to ten minerals of increasing hardness from talc to diamond. See page 10. See Chapter III.

Monochromatic. Possessing a single color.

Monochromatic Unit. A source of monochromatic light for refractive index determination. See Chapter V.

Monoclinic. A crystal system of low symmetry. Jade, spodumene, and orthoclase feldspar are monoclinic.

Opaque. Transmitting no light, even through thin edges.

Optic axis. A direction of single refraction in a doubly refractive substance. See Chapter VI.

Organic. Formed by a living organism—plant or animal.

Orient. The iridescent luster of a pearl.

Orthorhombic. A crystal system of fairly low symmetry. Described by three crystal axes at right angles, but unequal in length. Gems which crystallize in the orthorhombic system are topaz and peridot.

Paste. A name commonly applied to glass imitations. Used less often for other imitations. See Chapter XI.

Plastic. A manufactured organic product often used to imitate gems (especially amber) in costume jewelry.

Pleochroism. Unequal absorption of the two portions of a doubly refracted beam of light producing two or more colors when observed through a dichroscope.

Polariscope. A gem testing instrument employing two pieces of Polaroid to determine single and double refraction, pleochroism, and interference figures. See Chapter VI.

Polarized light. Light waves vibrating in a single plane. See Chapter VI.

Polaroid. Trade-mark name for a material which effectively polarizes light.

Radiograph. A photoshadowgraph by X-rays or gamma radiation of objects at least partially transparent to such wavelengths but opaque to visible light.

Reconstructed. A substitute made by consolidating fragments of natural material. A ruby substitute was once made by fusing ruby fragments or powder, and an amber substitute is still made by softening fragments with heat and forcing them through a screen.

Reflection. Rebound from a surface. Light which strikes a reflecting surface is reflected at the same angle to the normal as the angle of incidence. See Chapter V.

Refraction. The bending of light rays as they pass from one medium to another of different optical density at angles other than perpendicular to their boundary. See Chapter V.

Refractive index. The ratio of the velocity of light in air to its velocity in a substance. See Chapter V.

Refractometer. An instrument that measures refractive index. See Chapter V.

Silk. Term commonly applied to long needle-like crystal inclusions in natural ruby and sapphire.

Spectroscope. An optical instrument used for forming spectra.

Spectrum. The images formed when a beam of light (visible or otherwise) is dispersed and then brought to focus.

Specific gravity. The ratio of the weight of a substance to that of an equal volume of water at 4 degrees Centigrade. See Chapter IV.

Synthetic. A man-made substitute possessing the same chemical composition, crystal structure, and thus the same properties as the gem it represents. See Chapter X.

Tetragonal. A crystal system to which may be assigned two crystallographic axes equal in length and at right angles with a third at right angles to the first two. Zircon and idocrase are gems which occur in the tetragonal system.

Transparent. Transmitting light with a minimum of distortion.

Translucent. Transmitting light, but diffusely. Example: frosted glass.

Triclinic. The least symmetrical crystal system. Turquoise and most feldspars occur in this system.

Ultra-violet. That portion of the electromagnetic spectrum just shorter in wave length than visible violet light.

Uniaxial. Doubly refractive material with but one optic axis (direction of single refraction). Materials which crystallize in the hexagonal or tetragonal crystal systems.

X-rays. Radiation of .5 to 2.0Å. propagated in a cathode tube by bombarding a copper, tungsten, or other metal target with a stream of electrons. Useful because of their remarkable ability to penetrate almost any material. X-ray diffraction patterns from a given material serve to identify the material.

The Gemological Institute of America

Founded in 1931 by Robert M. Shipley, the Gemological Institute of America, known to most jewelers as the *GIA* or the *Institute,* is the educational, research and testing center of the jewelry industry. The purpose of this endowed, nonprofit organization is to provide professional training and other services for jewelers and gem collectors.

Educational Activities

The Gemological Institute's training is provided on a home-study, or correspondence basis; by classroom instruction; or partially by correspondence and partially in residence. Courses are offered on diamonds, colored stones, gem identification, jewelry retailing, and jewelry designing. After successful completion of the Diamond Course, the Diamond Certificate is awarded, or if the Colored-Stone and Gem-Identification Courses are completed, the Colored-Stone Certificate is awarded. When all three are completed successfully, the Gemologist Diploma is conferred.

The GIA Gem Trade Laboratories

The GIA Gem Trade Laboratories in Los Angeles and New York provide complete testing and grading facilities for jewelers and the public. In addition to routine testing, grading and determination of extent and cause of damage, they develop identification methods for new gemstone substitutes. Services are performed for many organizations, including the US Customs, the FBI, Better Business Bureaus, the Jewelers' Vigilance Committee, Chamber of Commerce, and insurance companies.

Special Instruments

A third function of the Institute is the design and manufacture of professional gem-testing and gem-merchandising instruments.

Included among the equipment familiar to most jewelers are the GIA Gemolite, Gem Detector, Illuminator Polariscope, Jewelers' Camera, Duplex Refractometer, Diamondlite, and Diamondlux.

Publishing

A fourth service is publishing reference works and *Gems & Gemology*, a professional quarterly in the field of gems and related subjects that has been published since 1934. A number of books and pamphlets also have been published. In addition to this book, some of the titles include *The Story of Diamonds, Famous Diamonds of the World, The Diamond Dictionary, A Roman Book on Precious Stones, Inclusions as a Means of Gemstone Identification,* and the *Dictionary of Gems & Gemology.*

Technical and Teaching Staff

The technical and teaching staff of the Institute consists of specialists who are trained and experienced in one or more of the fields of jewelry marketing, the sciences, education, and designing. Its policy-setting body is its eighteen jeweler-member Board of Governors, elected annually by the Sustaining Membership. The administrative head is the Executive Director, who directs the organization from its Los Angeles headquarters. The Board of Governors and other officers, except for the Executive Director and Executive Secretary, serve without compensation.

Facilities

The GIA has two locations. Its modern 10,000-square-foot headquarters building is located at 11940 San Vicente Boulevard, Los Angeles 49, California. The Eastern Division, including the Gem Trade Laboratory, maintains offices and classrooms at 580 Fifth Avenue, New York 36, New York. The home-study courses are conducted from the West Coast. Instructors from both facilities conduct diamond and colored-stone classes throughout the nation.

Acquiring Further Training in Gem Identification

One who seeks training in gem identification has three major choices: (1) he may gain the information from several gemological texts that are related to this subject in some degree, (2) he may take a correspondence course, or (3) he may study in residence.

If the choice is to pursue a course of study through a reading program, the following books are recommended: *Gemstones,* by G. F. Herbert Smith ($12.50); *Gems & Gem Materials,* by Kraus & Slauson ($6.95); *Gemstones of North America,* by John Sinkankas ($15); *Textbook of Mineralogy,* by Edward S. Dana ($8.75); *The Microscopic Determination of Nonopaque Minerals,* Larsen & Berman ($1); *Gem Testing,* by B. W. Anderson ($11.50); *Gemmologists' Compendium* ($3.35) and *Gems: Their Sources, Descriptions & Identification,* by Robert Webster ($32.50); and *Inclusions as a Means of Gemstone Identification,* by Edward J. Gubelin ($6.75).

The techniques of gem identification are covered in considerable detail in this work and in Anderson's *Gem Testing.* Despite the fact that both books deal with the same subject, the approach is somewhat different and the student should profit from both. *Gemstones* and *Gems & Gem Materials* provide further information on theory and, together with *Gemstones of North America,* serve to describe the gem materials in considerable detail. Larsen & Berman provides property values, including those of unusual materials rarely encountered by the jeweler, and the Dana textbook is useful for further descriptions of such gem minerals. This "do-it-yourself" approach to gemological education has the advantages of lower cost and that it can be used anywhere. It has the disadvantages of lack of assistance. when needed, and an absence of supervised identification practice.

A second choice is a guided home-study program, such as a correspondence course that provides identification instruction supplemented with practice in instrument use and testing techniques on a large number of stones selected for that purpose. Training by this method is less expensive than resident training, but slightly more expensive than merely reading books on the subject. The correspondence method permits a student to maintain his own pace and to follow a guided program that fits his needs. If a major portion of the program involves testing and identification of stones sent to him, there is no reason that the training received should not produce results equivalent to classroom instruction.

A third method is training in residence. Both correspondence and classroom instruction is offered by the Gemological Institute of America.

How to have Identifications Substantiated

Gemstones may be submitted for identification either to the Gemological Institute of America, 11940 San Vicente Boulevard, Los Angeles 49, California, or to the Institute's Gem Trade Laboratory at 580 Fifth Avenue, New York 36, New York. A moderate fee is charged for this service, plus return postage.

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Printed by
Premier Printing Co.
Fullerton, Calif.

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