SIXTEEN

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GEMS and GEMOLOGY

A Popular Presentation of the
SCIENCE OF GEMOLOGY
For the Amateur, Collector and Connoisseur

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a
GEMBOOK

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GEMS and GEMOLOGY

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Preface

So many people are becoming interested in rocks, minerals, and gems, that the public is becoming aware of gemology as a science.

While attending a school of engraving and jewelry manufacturing some years ago, I noted a surprising lack of information about gems and gem materials in persons actively engaged in the jewelry trade. A school instructor tried to convince me that corundum was the material from which grinding wheels were made! He had served many years in the trade as apprentice, jewelry repairman, and store owner. He knew about sapphire and ruby, but had never connected those varieties with their parent species — corundum. Many other instances of the kind could be mentioned.

Later, while working as an engraver I became more and more interested in the subject of gems and took up their study with the Gemological Institute of America. About 1951 the San Diego Mineral and Gem Society started a class in gemology and I became the first instructor. Other instructors were: Edward Soukup, Jeanne G. M. Martin, Edward Bohe, Pansy Kraus, Karl Sack, Jack Trott, and Fritz Jorrey. The classes are still in operation and are still popular.

In 1955, Don MacLachlan, editor of GEMS & MINERALS, heard of our gemology classes and induced Edward Soukup and me to rewrite some of the class lectures into a series of articles for the magazine. It ran continuously for three years and made a useful and fairly complete course in gemology.

The lessons were not aimed at the jeweler in particular so some subjects of special interest to the jewelry trade were omitted; for instance, diamonds, their imperfection grading and appraisal; information about the precious metals; and jewelry sales methods and ethics. While information contained in this course will be of great interest and help to the jeweler, it is probably the first book on gemology intended for the amateur collector and hobbyist.

The writing of the first few articles of the series was extremely difficult. Neither Mr. Soukup nor I was gifted or experienced in writing. But Mr. Soukup's stability and inexhaustible fund of common sense helped tremendously.

But well or poorly written, the articles were popular. Hundreds of letters were received. All were laudatory, some contained very helpful ideas.

As the articles progressed the need of property and data tables became acute. We started the compilation of refractive index, specific gravity tables, etc., intending to publish each table with its related article. But they got away from us. They almost became like the well known tail that wagged the dog. We wanted the tables to be accurate, but above all — usefully complete.

Every gemologist has experienced the frustration of trying to find data on the property of some not too common gem mineral. He may spend a lot of time looking in many books, and then not always find the required information. For example — try to find the dispersion of apatite!

The tables became so big it was impossible to include them with the articles, and it was necessary to publish them separately. They became the *Gem Materials Data Book*. Many thousands of copies of that publication have been sold.

When we started revising and modernizing the previously published articles for inclusion in this book, again we hoped to include all of the tables in the book. It just was not possible. We have included in the back of this book, all of the tables except the main table, the Master Data list. All of the identification tables, refractive index, specific gravity, color, dispersion, pleochroism, etc., have been included. But the Master Table, 27 large pages of useful information, will have to be obtained separately.

While writing the original articles a great deal of valuable help was received from several sources. Edward Bohe, G.G., F.G.A., completely wrote our chapter on color in gems. Jeanne Martin, C.G., F.G.A., of the Gemological Institute of America, gave helpful encouragement and corrected some gem data. All drawings are the work of Don MacLachlan, made from our rough sketches. In all cases he managed to increase the clarity and interest, whatever the subject.

Students in our gemology classes found the articles useful and made many helpful suggestions.

For those not familiar with the gemological title abbreviations commonly used, the following may be of interest:

G.G. — Graduate Gemologist. One who has satisfactorily completed all courses of the Gemological Institute of America.

C.G. — Certified Gemologist. A title annually awarded to members of the American Gem Society who have satisfied educational and membership standards required by that society.

F.G.A. — Fellow of the Gemological Association of Great Britain, a holder of the fellowship diploma of that association.

Charles J. Parsons

TABLE OF CONTENTS

Inclusions in Gem Stones, Continued . . .

Introduction

Gemology is an interesting and very rewarding subject for the gem and mineral hobbyist, covering as it does, some degree of both mineralogy and geology as well as the history of, and facts necessary for identification of all gem minerals.

Some knowledge of gemology is a necessity to the advanced collector, not only because it is an interesting part of his hobby, but for his own protection. Who, visiting a rock shop, has not seen a mineral he would like to have if he could be certain of its identity, quality, and cuttability?

Of course we know gem and mineral dealers are honest. But if a dealer buys a mineral under a certain identity from his supplier, he is likely to sell it under hat same identity, right or wrong. One dealer lost some prestige by innocently selling a pair of blue stones which he had purchased as part of a mixed parcel. They had been marked "kyanite" and he sold them for kyanite. This was fine until the lady purchaser had them checked by a gemologist and found they were glass! Of course she told him off in no uncertain terms and demanded her money back which was promptly forthcoming with suitable apologies, but the dealer lost a customer. This dealer has since found both pleasure and profit in learning gemology.

Several methods of studying gemology are open. First, and probably he commonest, is to purchase one or two books on the subject, study them avidly for a few evenings, perhaps look at the pictures once or twice more, then put them on the shelf and refer to them only when preparing a talk for the club. This is not sufficient study.

The second and of course the best method, is to take the complete correspondence courses and resident classes of the Gemological Institute of America. These courses are the finest obtainable and well worth their cost but are definitely not cheap, therefore not practical for all people.

Another method, much cheaper and less complete, is to study in the weekly gemology classes of the San Diego Mineral and Gem Society, open to all hobbyists but useless to those at a distance.

We hope that this book and its lessons (chapters) will offer another method, available to all, inexpensive, and as complete and practical as we can make it.

Now, a few words about other gemology books in relation to these lessons. No books published at the present time will adequately substitute for these lessons. Most books about gemology are written by professors of mineralogy or are aimed at persons in the jewelry trade and leave much to be desired in down-to-earth practical gem testing for the amateur and collector. However, certain books will be of interest and helpful in getting the most from these lessons, and the following are recommended:

Gem Materials Data Book, by Charles Parsons and Edward Soukup (Gems and Minerals). Its tables give all the useful data on gem materials and gem minerals, common and rare. It is of great value in practical gem identification. Some of its identification tables are reproduced in this book.

Dictionary of Gems and Gemology, by Robert M. Shipley (Gemological Institute of America). This dictionary will help throughout the lessons by defining and explaining gemological words and terms, giving descriptions and data on gem materials.

Handbook of Gem Identification, by Richard Liddicoat (Gemological Institute of America). Useful during identification practice for its gem descriptions, color lists, gem properties, and data lists.

Gems and Gem Materials, by Kraus and Slauson (McGraw-Hilll Book Co.).

Contains history and description of gems, particularly diamonds, diamond mining, and mineralogy for gemologists.

Gemmologists' Compendium, by Robert Webster. (N.A.G. Press Ltd.). Contains formulae, tables, color plates, and other valuable data.

Gemstones of North America, by John Sinkankas (D. Van Nostrand Co.). The only complete work available on the subject.

The Gemological Institute of America defines *gemology* as, "The science of those minerals and other materials, beautiful enough and durable enough for use as personal adornment, and for the embellishment of our personal possessions." It divides the science into four divisions:

1. *Descriptive Gemology* which includes classification of gem materials and their substitutes; precious metals, their alloys and substitutes; sources; and methods of fashioning and use.

2. *Determinative Gemology* covering information and data necessary for the scientific identification of gem materials and their substitutes.

3. *Historical Gemology* treating the history of gem materials and their use in jewelry and other ornaments.

4. *Ethical Gemology*, the study of correct and incorrect nomenclature and its ethical representation.

We will cover the first two divisions thoroughly enough to give the student a practical, working knowledge of the subjects. The last two divisions will be covered only as they apply to the amateur and hobbyist.

The material presented here was originally published serially in GEMS AND MINERALS, a monthly magazine. Each installment was presented as a lesson. We have maintained the primary form of the material in this book and by studying the chapters in sequence, the student will, in effect, study an organized "course" in gemology. While the various chapters can be read separately, it is strongly recommended that the material be studied in the sequence presented so that a proper background will be obtained before working with later chapters.

If the student follows the sequence of chapters to completion, he will cover approximately the same ground presented in the first year gemology classes of the San Diego Mineral and Gem Society.

A Note On Spelling

You will find both *gemmologist* and *gemologist* in the literature. The spelling with two "m's" is preferred by the British; one "m" is the American preference.

Gem stone or *gemstone?* Merriam-Webster *New International Dictionary*, unabridged (1956), gives *gem stone*, two words, as the preferred spelling.

Chapter 1

About Gemology

The word *gemology* is derived from the Latin word *gemma,* a gem, and *logos,* a Greek word for discourse.

As a science, gemology should be considered as a distinct entity, never as a specialized branch of mineralogy or geology. Although it is derived from several major sciences, principal among which is mineralogy, there is a notable difference between gemology and these sciences in their respective identificaion procedures.

Mineralogy, by the use of thin secions, pulverized samples, chemical analyses, etc., often destroys all or part of the specimen. Gemology, identifying cut stones most frequently, is unable to do this and finds it more practical to use optical methods which do not injure the specimen. It even frowns heavily on the use of a hardness test. Subjects such as organic gem materials (pearl, coral, amber, jet), synthetic gem materials, diamond grading, gem fashioning, etc., are of no interest to the mineralogist but are a necessary part of gemology.

In England, about 1908, the word *gemmology* was first used by the National Association of Goldsmiths when t instigated research to obtain better methods of gem identification. Prior to that time mineralogical methods, quite unsatisfactory for gem identification, had been used. The N.A.G. formed the Gemmological Association of Great Britain which organized courses and gave examinations leading to the title, "Fellow of the Gemmological Association of Great Britain," and entitled the holder of the diploma to use the letters, "F.G.A." after his name.

In this country, a widely experienced retail jeweler, Robert M. Shipley, after graduating from the British classes in 1931, organized the present Gemological Institute of America with headquarters in Los Angeles and a branch in New York. Many amateurs and hobbyists, including the authors of these lessons, have studied its courses which at the present time are the most comprehensive known.

Our course cannot and will not attempt to be as comprehensive as the Institute's course. For one thing, we shall cover only those subjects of interest to the hobbyist, amateur and collector and omit such material as merchandising, etc., that is of interest only to the commercial jeweler.

In The Beginning

We can only surmise the earliest use of gems by mankind, but it seems easy to picture Og, the Dawn Man or a near relative, lying flat for a drink from the creek which gurgled past his cave. Noticing several large, transparent, red rocks in the creek bed and having bitten them and found them inedible but very beautiful (rubies, no doubt!), he may have carried them to his cave. At some later time he devised some method of twisting and braiding them with fiber to form a necklace.

Or, as suggested by others, pearls may have been the first gems used by man. Our man may have lived near an ocean where there were pearl-bearing molluscs. Using them to supplement a diet of dinosaur steaks and iguanodon eggs, he would find an occasional pearl when cracking open the oysters on a convenient rock. Sooner or later, he saved some for the adornment of himself or his family. Whatever the true story, it is certain that man treasured gems, perhaps tumble-polished in some creek bed or in one of their many rough forms, long before the dawn of written history.

In man's earliest recorded history gems were coveted not only for their beauty, but, perhaps, even more for their supposed ability to ward off evil spirits and to bring good fortune. Gems have played their part, and a major part, in the history of nations and will probably continue to do so as long as they remain such a concentrated and easily transportable form of wealth. In what other form can a man put a half-million dollars in a Bull Durham tobacco sack?

Factors Affecting Value

What are the factors affecting the value of gem stones? Why are some stones worth a dollar and others perhaps 10,000 times as much?

Beauty, durability, and *rarity* are said to be the prime factors of gem value. But two additional factors may be added: *vogue* and *fashioning.*

It is generally conceded that beauty is the most important, but without the first two, beauty and durability, no material can be classed as a gem. Rarity does not always create high value in a gem, but without it no gem can reach high value. Andalusite and euclase, both rare and beautiful, are not of high value because the general public is not fully aware of them and there is not a sufficient supply to create a demand.

Vogue, fashion, or public acceptance is a large factor in determining value. The diamond is always fashionable and commands very high prices. But opal, perhaps the world's most beautiful gem, is valued at only a few dollars per carat. The highest price known to have been paid for opal is about $500 per carat. For diamond, the highest price paid for a colorless stone was $15,000 per carat for a stone of about ten carats. Both of the cases above were extremely unusual. The famous Hope blue diamond, weighing 44.5 carats, valued by Harry Winston at a million dollars, would be over $22,000 per carat. (The Hope diamond is now in the U. S. National Museum.) To be fair in this comparison, we should also consider the respective durability of opal and diamond.

The fifth factor of value, fashioning or cut, is a more stable factor in that all gem values are based on stones of perfect cut which will bring out the best in brilliancy and beauty of the variety. Any stone less than perfect in cut will be proportionally less in value. An imperfectly cut stone will probably never be of high value.

Obsolete, but terms still frequently used when referring to certain gem stones, are *precious,* and to those of lesser pedigree, *semiprecious.* Considerable discussion and controversy occurred regarding these terms during the earlier years of this century but no definite dividing line could be agreed upon.

The most common group classified as precious included diamond, ruby, emerald, sapphire, and pearl, all others being classified as semiprecious. This was never completely satisfactory to the jewelry trade nor understood by the public, as poor quality rubies might be purchased for a few dollars while some fine stones of varieties not classed as precious, such as opal, chrysoberyl, or topaz, might be valued in thousands of dollars. Many sales have been lost when some inquiring customer, perhaps looking at a fine chrysoberyl cat's-eye, asked whether the stone was a "precious stone." and lost interest when informed that it could be called only "semiprecious."

These terms are rightly falling into disuse and it is strongly recommended that all gemologists avoid them and discourage their use when possible. It would probably be better to refer to all cut stones as *gem stones,* or, if it is found desirable to use the word "precious," let it refer to *all* gems, since to be classed as a gem it must be beautiful, and a thing of beauty should always be precious.

Additional Reading

These books, if available at your library, will be found to be interesting, supplementary reading:

Gemstones of North America by John Sinkankas (D. Van Nostrand).

Gemstones, by G. F. Herbert Smith (Pitman).

Precious and Semi-Precious Stones, by Michael Weinstein (Pitman).

The World of Jewel Stones, by Michael Weinstein (Sheridan House).

The Curious Lore of Precious Stones, by G. F. Kunz (Lippincott).

The Story of Gems, by H. P. Whitlock (Furman).

(Note: The book by Kunz is out of print.)

hapter 2

ems and Their Names

Those who wish to get the most from ese lessons should make a decided ffort to become well acquainted with e proper names for gems, learn when use the group names and when to se the species or variety names. Even e incorrect and false names in general se should be learned, for, as Shakes- eare said about bad words, "We ould know them, if only to avoid em."

It is quite unnecessary to memorize e complete list of gem names. It might done, but the information probably ould not be retained. Learning by fre- uent use and by fostering a consistent terest in the subject is more efficient an sheer memorization. As a matter f policy, form the habit of checking a gem dictionary or tables, all un- miliar gem names met in read- g or conversation. Learn whether the ame indicates species or variety. A rprisingly large and accurate fund of m information will be acquired pidly.

Species And Variety

A *species* is a division of minerals aving, in general, the same properties, ysical and optical. Minerals of the me species must have the same re- active index, specific gravity, hard- ss, and chemical composition, al- ough they may, and often do, differ idely in color, form, and transparency. hemical composition of a species may ry to some extent with variations in loring oxides and inclusions.

A *variety* is a subdivision of a spe- es. Varieties of a species differ in me item of appearance only, such as lor, phenomena, or transparency. As example, the species *corundum* is not ry well known to the general public. ut, very well known, indeed, are the o varieties of that species, *ruby*, a edium red gem, and *sapphire*, blue any color other than medium red.

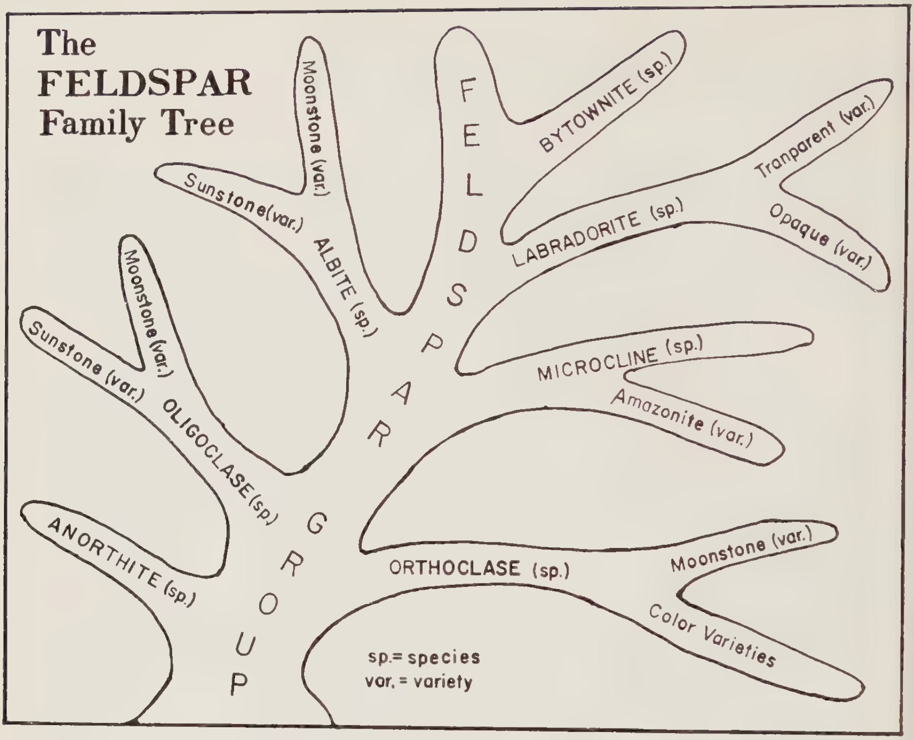
Another example is the species *chrys- beryl.* Chatoyant *cat's-eye* is probably the best known variety. *Alexandrite,* with its day to night color change from green to red is a close second. There are also two lesser known varieties: *cymophane* and *chrysolite chrysoberyl.*

During many years of use by man, some individual gem stones have acquired a surprising list of names, all of which should be familiar to the gemologist. For instance, the translucent gem mineral *idocrase,* often used as a jade substitute, has three additional names, all in common use: vesuvianite, californite, and "California jade." *Iolite* also has three additional names: dichroite, cordierite, and "water sapphire." In both of the above examples, the first name given is believed to be most suitable for gemological use.

A laudable effort is being made by mineralogical authorities in this country and Europe to apply the suffix "ite" to all official mineral names. Luckily, no attempt is being made to modernize the names of older gems so well known in song and history. One would shudder to think of such names as "sapphirite" or "diamondite." And if "rubyite" were used it would bring to mind our long dead Persian friend, Omar Khayyam, rather than a beautiful, red stone.

There is also a rather deplorable tendency for rockhounds and others to append "ite" to the name of a discoverer or location of a newly found color or pattern variety of some well known mineral species. This only causes confusion as the names almost never reach accepted status in the literature and when one tries to look them up there is nothing but a void of information. In such a case it would be far better to attach the name of the discoverer or the locality to the correct name of the species or variety and not attempt to create a meaningless, and usually soon forgotten, new name.

Mineralogy names and recognizes 1500 to 3000 species, the number differing with different authorities. Luckily,



only about 75 to 100 species are listed as *gem* minerals, about thirty of which are of major importance to the jewelry trade.

Groups

A division of minerals *closely related chemically* is called a *group*. In England, the term *family* of minerals is used.

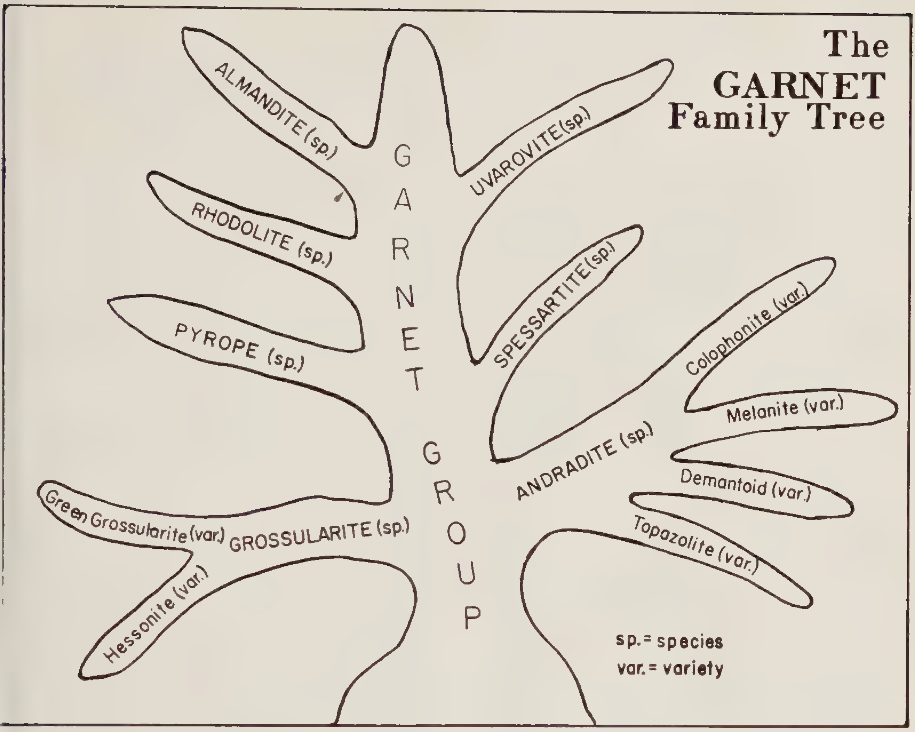
Only two groups are recognized in gemology: the garnets, and the feldspars. The garnet group includes the following species: almandite, rhodolite, pyrope, grossularite (varieties—hessonite and green grossularite or "Transvaal jade"), spessartite, uvarovite, and andradite (varieties—demantoid, melanite, topazolite, and colophonite).

The feldspar group includes the species: orthoclase (varieties—moonstone and color varieties), microcline (variety—amazonite or amazonstone), albite (varieties—moonstone, sunstone), oligoclase (varieties—moonstone, sunstone), labradorite (varieties—opaque labradorite, transparent labradorite), bytownite, and anorthite.

Much to be deplored is the current practice of a few irresponsible rock shops that are selling *any* species of transparent feldspar as sunstone. True sunstone or *aventurine feldspar* is usually a variety of oligoclase. Certainly, to be called sunstone, it should have sufficient inclusions of hematite or goethite to cause the reddish, almost metallic, cast or "sun" in the stone when viewed from the proper direction.

A rather peculiar naming situation exists in regard to the mineral quartz (SiO_2). The world's most common mineral is of two distinct types differing greatly in structure and appearance but *chemically the same.*

Some believe that quartz should be classed as a group along with garnet and feldspar. But, a group consists of minerals closely *related* chemically, while the two types of quartz are chemically the *same.* The two types of quartz differ in appearance and form and each has ten or more varieties. They are classed as *subspecies* of the species quartz. Many persons prefer to simplify the matter and call each type a species by itself. The two subspecies are *crystalline quartz*, and *cryptocrystalline quartz* or *chalcedony.*



Note the many varieties under each ype in the property and data tables. In ddition to the names given, there are nany more locality or descriptive names n use by rockhounds, such as *plume gate, Texas agate,* etc.

Gem Names As Colors

In addition to understanding groups, pecies, and varieties, it is important to nderstand, and use correctly, certain em names often used as indicators of olor. There are several such names hich may be used to indicate a gem olor, as *topaz, chrysolite, ruby,* and *yacinth.* Such names may be used if sed ahead of the name of the true mineral, *but never after it.* It is permissible o use *topaz quartz* but not "quartz opaz" to indicate yellowish citrine uartz.

Chrysolite, a mineral species known s olivine to geologists and peridot to emologists, is frequently used to indicate a color of yellow to yellowish reen as in *chrysolite chrysoberyl, chryslite beryl,* and *chrysolite sapphire.*

Ruby, a variety of corundum, is often sed to indicate the color of other red o purplish-red stones, as in *ruby spinel* and *ruby glass.* But it should never be used as "spinel ruby."

Hyacinth or *jacinth,* an orange to orange-red variety of zircon, is often used to indicate similarly colored hessonite, as *hyacinth garnet.*

At such times as it may be found necessary to use a deceiving name for a gem mineral, it is customary to place the name in quotes, as "topaz" or "quartz topaz" when applied to citrine quartz. This will be done throughout these lessons.

Pronunciation Of Names

We believe it is unnecessary to give pronunciations for all gems and minerals. Certainly everyone can pronounce feldspar, quartz, diamond, etc. The list of names on page 21 is intended to cover only those minerals often mispronounced or of a controversial nature. It would be impossible to list all 3,000 minerals here, but we have listed those believed to be of greatest interest to collectors.

Many misuse the word beryl, pronouncing it "berl" or "burl" instead of bear-ill to sound like "burial" with the "i" left out, although most of them know it to be wrong. The urge to mispronounce this word may be like that of the young sailor who attempts to use the saltiest words on his first trip to sea.

A word most frequently mispronounced is chalcedony, the popular pronunciation of the uninformed, including many ministers, is CHAL-se-do-nee, giving the CH a soft sound as in chest, instead of a kal-SED-o-nee which is correct.

In the list given on page 21 we will not use the standard dictionary pronunciation marks, but will spell out the syllables for pronunciation and indicate the accent syllable by capital letters.

False Names

False or deceiving gem names are often met in the jewelry or gem trade. The commonest misuse is probably topaz. Topaz is a well known gem mineral species with a definite chemical composition. It is found in many parts of the world, in many colors, the best known of which is orange-yellow. But for many years the jewelry trade in both the United States and Europe has sold orange-yellow or citrine quartz under the name of "topaz." The custom is still common among the older jewelers as well as the unethical but it is prohibited by U. S. Federal Trade Commission regulations. Needless to say, no deceiving term would ever be used by anyone sufficiently trained in gemology to understand and apreciate the necessity of correct gem terminology.

Another deceiving term often used is "olivine" or "jewelers olivine." It is used as a name for demantoid, the green variety of andradite garnet. It is rather difficult to understand why this persists since demantoid, on the present market. is worth much more than true olivine, or peridot as it is termed in gemology.

In one case, a deceiving name seems almost necessary as no other variety name has come into common use. This is for the translucent, green, grossularite garnet commonly called "Transvaal jade" or "African jade." The name gooseberry garnet or gooseberry stone has been used but it is not popular. Perhaps it would be better to merely call it green grossularite.

Here are some of the commonest false or misleading gem names.

False Gem Names

"AFRICAN JADE"—translucent, yellowish-green grossularite garnet.

"ARIZONA RUBY"—pyrope garnet.

"BALAS RUBY"—pink or rose-red spinel.

"BLACK MOONSTONE"—labradorite.

"BRAZILIAN RUBY"—red or pink topaz, also tourmaline.

"BRAZILIAN EMERALD"—green tourmaline.

"BRAZILIAN SAPPHIRE"—light blue topaz, also tourmaline.

"CALIFORNIA JADE"—idocrase.

"CANADIAN LAPIS"—sodalite.

"COLORADO JADE"—amazonite, a microcline feldspar.

"EVENING EMERALD"—peridot.

"JEWELERS OLIVINE"—demantoid garnet.

"KANDY SPINEL"—almandite garnet from Ceylon.

"KOREAN JADE"—bowenite, serpentine, or sometimes soapstone.

"LITHIA EMERALD"—hiddenite, green spodumene.

"MATARA DIAMOND"—colorless zircon.

"MEXICAN ONYX"—certain types of calcite or marble.

"OCCIDENTAL TOPAZ"—citrine quartz.

"ORIENTAL EMERALD"—green sapphire.

"ORIENTAL AMETHYST"—violet sapphire.

"PINK MOONSTONE"—scapolite.

"SLAVES DIAMOND"—colorless topaz.

"SMOKY TOPAZ"—smoky quartz.

"SUCHOW JADE"—bowenite, serpentine, sometimes soapstone.

"SPANISH TOPAZ"—citirine quartz.

"SPINEL RUBY"—red spinel.

"SWISS LAPIS"—blue dyed jasper.

"TOPAZ"—citrine quartz.

"TRANSVAAL JADE"—translucent, yellowish-green grossularite garnet.

"WATER SAPPHIRE"—iolite.

"URALIAN EMERALD"—demantoid garnet.

"HERKIMER DIAMOND"—rough rock crystal quartz, doubly terminated, from Herkimer County, N.Y.

hapter 3

he Genesis of Gems

An interesting part of gemology is a tudy of the origin or methods of for- ation of the minerals from which ems are cut. More fully covered by the ciences of geology, petrology, and min- ralogy, it could merit more space than e are able to give it here. For those nterested in further study, the following ooks are suggested: *Physical Geology* y Longwell, Knopf, Flint (John Wiley nd Sons); *Igneous and Metamorphic* *etrology* by Turner and Verhoogen McGraw-Hill Book Co.); *Introduction* *the Study of Minerals* by Rogers McGraw-Hill Book Co.).

There are three important methods f mineral and rock formation: (1) By sion or the *igneous process.* (2) rom solution and deposition or the *edimentary process.* (3) By alteration r *metamorphic process.* Each will be xplained briefly.

Let us note here the difference be- ween rocks and minerals. Kraus defines inerals as: *A natural, inorganic sub- ance with a characteristic chemical omposition, usually possessing a defin- e crystalline structure sometimes ex- ressed in external geometrical form.* ther authorities have slightly different finitions, some insisting on a definite ystal structure, terming the amor- ous, mineral-like substances such as al, limonite, and psilomelane, *min- aloids.*

So, to be classed as a mineral, a sub- ance must: (1) Be *made by nature,* naided by man. (2) Be of *inorganic* *igin,* not the result of the activities living organisms. (3) Be a *homo- neous substance* with a *definite chem- al composition,* that is, it must have a niform structure and the chemical mposition sufficiently constant to be pressed in a chemical formula to as- re constant physical and optical prop- rties.

For the purpose of gemology, no em- asis is placed on the definite crystal structure. We may therefore call opal a mineral with impunity.

A *rock* is a geological unit, comprising a large part of the earth's crust, consisting of *one or more minerals.* The properties of rocks may vary widely. Rock consisting of a single mineral, such as marble (calcite), has fairly constant properties, but granite, made up principally of quartz, feldspar, and accessory minerals, shows widely differing properties as the proportions of the minerals vary. Everyone has seen granite so soft as to crumble in the hand and other specimens hard enough to scratch good steel.

Rocks are of interest to the gemologist since many of the finest gem minerals are formed in rocks. We often use the word *matrix* or "mother-rock." The fine, blue gem, lapis lazuli, is a rock consisting principally of the minerals lazurite, calcite, pyrite, and several others in lesser percentages.

The Igneous Process

Rocks formed by the igneous process are especially important because they are the original source of the other two groups of rocks, the sedimentary and the metamorphic.

Rocks in melted form, called *magmas,* are often of complex chemical composition. They reach very high temperatures, causing vaporization of metallic, aqueous, and other more volatile components. These gases, permeating the magma, maintain it in an extremely liquefied state which, combined with high pressures, assures its escape and transportation to points of lower pressure where cooler surroundings, lower pressures, and time permit cooling and solidification.

It might seem at first that the sequence of solidification would follow down the chain of melting points of the elements, those having the lowest melting point solidifying last. This is not entirely true. It is considered that the

A tourmaline group from the San Diego area. From the collection of Bill Woynar, San Diego, Calif.

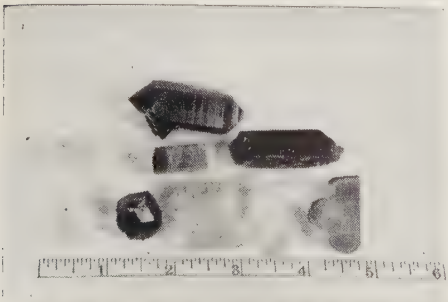
elements will solidify in the reverse order of their *solubility* in the solution of fluid magma. To illustrate this point, consider the mineral quartz (SiO_2), the melting point of which is 1470°C or 2678°F. But quartz is quite easily *soluble in water* at a temperature a *little over half* its melting point.

The Pegmatite Dike

One of the best producers of gem minerals is the *pegmatite dike* which is second only, in value of gem production, to the diamond pipes and alluvials.

The word *dike* indicates a wall-like intrusion which cuts across the bedding of other layered strata of country rock. Usually vertical or somewhat inclined, it could be horizontal if it cut across the bedding planes that had been tilted to a vertical position. (If an intrusion parallels the bedding planes, it is called a *sill.*)

The word *pegmatite* is variously defined by different authorities. *Standard Collegiate Dictionary* says it comes from the Greek *pegma, "something fastened together."* As used in petrology it alludes to the quartz and feldspar of graphic granite, a coarse variety of granite occuring in dikes or veins. Also, it may refer to the same formation of other rocks such as syenite granite.



Tourmaline, beryl, smoky quartz, epidote, garnet and topaz, all found in the gem pegmatites.

The Dictionary of Mines and Mining defines it as, *"Giant granite,* or an igneous rock, irregular in texture and composition, composed mainly of silicate minerals of large size, including quartz, feldspar, mica, beryl, tourmaline, lithia minerals, zircon, etc., and may carry rare earth metals."

Chambers' *Mineralogical Dictionary* has a slightly different version. "Name originally applied to rocks with intergrowth of feldspar and quartz, as graphic granite, but now applied to igneous rocks of any composition, but of coarse grain, occurring as offshoots from, or veins in, larger intrusive bodies, representing a flux-rich residuum of the original magma."

Shipley's *Dictionary of Gems and Gemology* gives the gemological version of the pegmatite: "Coarse grained, igneous rock mass, usually in the form of a dike which, during slow solidification, contained rare gas or vapors which aided in forming especially large, well formed crystals of which aquamarine, spodumene, topaz, tourmaline, and transparent quartz are of gemological importance."

The word pegmatite alone could mean a graphic granite dike or almost any coarsely grained rock in that type of formation. If we are more specific and call it a *gem pegmatite,* it would then most certainly indicate the type mentioned by Shipley. There may be many pegmatites but there are only a few gem pegmatites.

It may be interesting to go a little farther in regard to pegmatites and consider "how they got that way."

As mentioned earlier, a magma usually has a very complex chemical composition. As heat from the body is lost and solidification commences, those elements last to liquefy and become part of the magmatic solution will be the first to solidify. Solidification and consequent shrinkage inevitably cause cracks into which the still liquid elements can e forced. The term *end products* has een applied to the last elements to olidify. The rarer elements that make p these end products have undergone concentration process by the removal f those elements already solidified and eing well below the earth's surface, ould have ample time to cool *slowly* nd form large, well shaped crystals. his, in effect, is the way gem pegatites are formed and how we get uch of our beryl, spodumene, topaz, ourmaline, and transparent quartz.

Incidentally, diamonds are never ound in pegmatites.

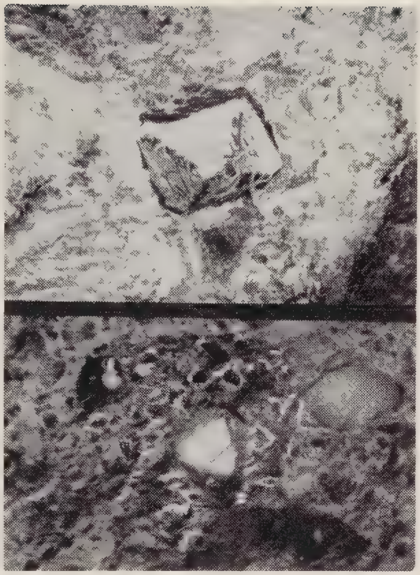
Other Igneous Minerals

Other methods of mineral formation y the igneous process are generally milar to those forming pegmatites esntially the crystallizing out of solution pon reduction of temperature, pressure, r both. High school chemistry students ave all performed the experiment of issolving table salt in water until no ore can be dissolved. Then, by heating e solution, considerably more of the lt can be dissolved. In this condition, e solution is said to be supersaturated. pon cooling, the excess salt is prepitated from the solution. If cooled pidly, the excess salt collects on the ottom of the container in no particular rm. But if cooled very slowly, the salt ill gradually form into large clear ystals.

For the forming of gem minerals, the quired concentration of chemical eleents must be present as well as the oper conditions of temperature and essure. If cooling is sufficiently slow, it would be deep below the earth's rface, large, well formed crystals relt. But, if cooling is too rapid, such in lava after the eruption of a volno, the same elements may solidify o rapidly with no opportunity to ystallize. Obsidian or volcanic glass fine-grained rocks are then the result.

Diamonds

And now we come to the most imrtant of all gemstones, the diamond. nportant, that is, to everyone except e rockhound, who calmly shakes his ad athwartships rather than fore and t, and says, "Huh uh, not having any." Jewelers usually genuflect automatically each time the word is spoken. Rockhounds remain completely uninterested, except, of course, for the time each adult male must, through force of biological circumstances, make his contribution to the Diamond Trust. It may be a "sour grapes" attitude on the part of the rockhounds, diamonds not being found on field trips. But the diamond is a fine and unusual gem of igneous origin, so we will briefly review its theoretical methods of formation.



A diamond in its kimberlite matrix, from Kimberley, South Africa. From the collection of Ralph W. Dietz.

I say theoretical because as yet, no theory of the formation of diamond is universally accepted. This, of course, may soon be changed following the big stride made by General Electric Company in synthesizing the diamond.

The diamond pipes of South Africa were formed some 60 million years ago. As a source of gems they are of first importance in gemology with pegmatites definitely secondary. The shape of the so called diamond pipes are usually roughly circular. They have a surface diameter up to several thousand feet, but narrow quite rapidly as depth increases. They are funnel-shaped vents of ancient volcanos which remained filled with cooling magma, called kimberlite, when the forces below became too weak to force the vent clear. But as to how and when the diamonds were formed or found their way into the kimberlite, no one as yet seems certain. A supply of pure carbon, high heat, and pressure seem necessary factors. These conditions have been verified by General Electric Company in its synthesis of diamonds.

Some of the earlier superstitions or theories concerning diamond formation are rather weird but interesting. Certain Chinese communities believed diamonds to be gifts from heaven, deposited during heavy rainstorms, and that diamonds not found would continue to grow after each rain until large enough to be easily seen. They gladly harvest those found on the surface, but nothing will induce them to dig below the surface for more, believing that it would be extremely bad luck to do so.

In India, the Hindus believed diamonds were quartz crystals transformed into diamonds by bolts of lightning.

More recently, early British scientists theorized that diamonds were formed by an organic process, like that of the tabasheer opal sometimes found in the joints of bamboo, or that they were formed by a process in which they were plastic at an early stage.

Current theories are that they were formed about 60,000,000 years ago in deep seated plutonic reservoirs under very high pressure and temperature and, being first to separate from the magma, would have full opportunity for crystalline development and perhaps transportation to distant points in the still fluid magma. Finally, they found an outlet to the surface through a volcanic vent. Here they were later found in the matrix called kimberlite.

Another current theory supposes them to have been formed and solidified in some deep plutonic rock which at a later period was fused or disintegrated, after which the diamonds became part of the kimberlite.

Or, some say that the diamonds were crystallized at some point during the time the kimberlite was solidifying in the vents we now call diamond pipes. This might account for the fact that no diamonds have ever been found in a surface lava flow.

The late Dr. Sydney H. Ball summed it all up when he remarked, "None of us were there when it happened."

Diamond sources are world-wide, being known on every continent. However, they are mined in commercial quantities only in Africa and South America.

Sedimentary Process

The process of erosion by which the surface of the earth is softened, broken up, and slowly removed by the action of the weathering agents, water, wind, and frost, may in time uncover even deeply buried rocks. In this process of decay and disintegration the loosened particles are carried by wind, water, or glaciers to places of stagnation such as lakes or oceans. Here they are deposited, forming layers or beds of sediments which are sometimes compacted into sedimentary rocks.

It may be difficult to believe that these weathering agents can wear away the hard rock masses of some towering mountain peak and will, in time, actually reduce the peak to the level of the surrounding plain. Or that igneous activities may elevate the lowest levels of former lake or sea beds to the status of a mountain peak. The highest peaks in the Alps are of sedimentary material deposited in an ancient sea. Our own Sierra Nevada has such sedimentary rocks at very high elevations.

It is seldom that gem minerals are actually formed by sedimentation. But all minerals formed in the original igneous rocks may be released by weathering and transported to a place where they become part of a sedimentary formation.

During their period of transportation, when the mineral fragments are grinding against each other, the softer varieties are completely reduced and a large portion of the harder varieties reduced to tiny grains of sand. Bedded sand may be compacted and cemented into rock (sandstone) by any of the common natural cements such as silica, calcite, or iron oxide. When larger fragments are present, these rocks are termed *breccia* or *conglomerate*. Breccia is composed of angular, sharp-edged fragments, while conglomerate is made p of rounded fragments cemented toether.

Breccia and conglomerate, when comosed of contrasting or highly colored ragments, are collected and prized by ockhounds, both as rock specimens nd for cutting into gems.

Many fine gem minerals of igneous rigin, because they are harder than ost rocks and better fitted to survive e intense battering and grinding of eir travel to a resting place, are to e found in sedimentary formations. n Brazil, where diamond pipes are unnown, diamonds are found in gravels nd conglomerate.

Alluvial Deposits

When minerals are found in unceented sedimentary deposits such as iver beds, they are called *alluvials.* Diaond mining in Brazil is largely from is type of deposit.

South Africa has many alluvial minng areas. For years, alluvial minng was carried out before the first iamond pipe was discovered. In very ecent years, the story was told of cerain sections of an area in western South frica so loaded with diamonds that one erson could pick up a lunch box full a few hours.

The owners of this property say these ports are grossly exaggerated, that ere are very few areas where the diaond-bearing gravel is on the surface, nd that most of it is covered by 18 to 0 feet of overburden. At any rate, it being worked with modern bulldozers nd other equipment. It is fenced with everal rows of electrified barbed wire nd is well policed.

Many gem minerals other than diaond are found in alluvials. To menon a few: andalusite, beryl, cassiterite, hlorastrolite, corundum, garnet, jade, eridot, quartz, spinel, thomsonite, touraline, and zircon.

Chemical Sediments

Chemical precipitation produces anther group of sedimentary minerals nd rocks. *Limestone* (calcium carbonte) may be composed of the shells of ea animals. Coral is of this variety, ut since it is the result of the activities f living organisms, it is not a mineral ut is termed an *organic gem material.*

Travertine, a good example of chemically deposited sedimentary gem material. From the collection of Marian Dugger, gemologist, San Diego, California.

Travertine is a limestone of mineral origin. It is deposited by certain heavily mineralized springs and rivers. Travertine, an ornamental stone, is used extensively for carvings, book ends, ash trays and other useful objects.

Geodes, *agate*, and all varieties of *chalcedony* quartz, are deposited by solutions containing silica.

Petrified wood and most substances spoken of as fossilized are materials, originally organic, in which the individual organic cells have disintegrated and been replaced, cell by cell, with silica, the cells maintaining their original form and appearance. This process is called silicification.

When coral is silicified it is called *beekite.* Beekite has little significance as a gem material but is used in various ways in jewelry making. *Petoskey stone* is fossilized coral from the vicinity of Petoskey, Michigan.

Colloidal silica, deposited on sea floors in the form of a jellylike mass, when hardened becomes *opal.*

Chalcedony, a cryptocrystalline form of quartz, is considered by many authorities, in both this country and England, to consist of many submicroscopic crystals of crystalline quartz, cemented together with opal. This seems very logical if we compare some of the properties of quartz, chalcedony, and opal. Refractive index: quartz 1:54-1.55, chalcedony 1.535, opal 1.45. Specific gravity: quartz 2.66, chalcedony 2.60, opal 2.20. The admixture of quartz and opal might account for the somewhat lower range of chalcedony compared with quartz.

Both quartz and opal are of similar chemical composition (silicon dioxide, SiO_2) but opal is amorphous and includes 2 to 10 per cent water in its composition. The formula for opal is usually written SiO_2nH_2O, the "n" indicating a variable quantity of water.

Petrified wood and petrified shells (forms of chalcedony) may become partially or wholly opalized. This may be explained by considering that the tiny quartz crystals, in losing their crystalline nature, will become an amorphous form of silica containing water, which is opal.

Some authorities consider this alteration to occur in the reverse order. That is, in the replacement process of the wood cells by silica, the cells first become opal which upon crystallization of certain portions, become chalcedony. Specimens containing both opal and chalcedony are common.

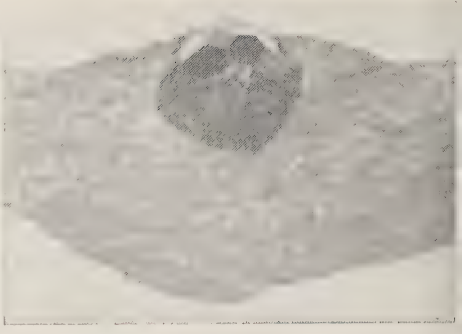
Both *limonite*, ($2Fe_2O_3.3H_2O$) and *hematite* (Fe_2O_3) are iron ores, often of sedimentary origin, being deposited in caverns, still ponds, or swamps. Hematite, as a gem material, is most frequently used for cameos or intaglios in men's jewelry.

Gypsum (calcium sulfate and water, $CaSO_4.2H_2O$), is deposited from water during the drying out of inland seas. A fibrous variety, *satin spar,* is used as an ornamental stone. *Alabaster* is a fine-grained variety of gypsum.

Turquoise is a complex copper-aluminum mineral ($CuO\ .\ 3Al_2O_3\ .\ 2P_2O_5\ .\ 9H_2O$) chemically deposited in veins or fissures, often too thin for use. Lately these hitherto unusable materials have been finding a market, in any quantity or quality, for grinding and mixing with a plastic binder in the manufacture of a turquoise substitute.

Metamorphic Process

The third of the three prime methods of mineral and rock formation is one of alteration, called *metamorphism*. The word means *transformed.*



This garnet in a schist matrix is a "classic" example of gem material formed by metamorphism. This specimen is typical and though no location was given, is probably from Alaska where many fine specimens of this type have been found.

Such transformation can occur to minerals of sedimentary or igneous origin or to those previously formed by metamorphism.

This action is the result of nature's attempt at adjustment to meet a changed environment. Minerals, quite stable under certain conditions of temperature, pressure, and composition, finding themselves under greatly changed conditions, strive or are forced to meet the requirements of that changed condition.

Sediments formed near the earth's surface may be subjected to folding of the crust or they may slowly subside and be covered with many thousands of feet of later formations. Under such conditions temperatures would increase and pressures would be very high. When pressure is high, nature attempts to relieve that pressure by altering the minerals to a more compact form. Garnet is often termed a space-saving mineral. Since it is of higher density, it actually occupies less space than did its components before alteration. All minerals formed under high pressure are characterized by high specific gravity.

Temperature is probably the most important factor in metamorphism. The speed of chemical reaction increases with temperature rise. Certain reactions cannot occur until a critical temperature has been reached. The amplitude of atom vibration increases with the temperature, which increases plasticity.

Increased temperature may occur either by deep burial in the earth or by the intrusion of a hot, igneous mass. Deep-seated magmas, under high pressure, may vigorously seek outlets to relieve the pressure. The fluid or plastic rock (magma) may find its way through vertical cracks or between horizontal bedding planes of prior formations. The intrusion usually causes an increase in both temperature and pressure in the surrounding rock. This results in appropriate changes in the rock directly in contact with the magma and, to a gradually lessening degree, to the rocks near the intrusion.

This is called *igneous* or *contact metamorphism.*

New substances may aid in metamorphic change. Igneous masses, having vaporized certain components such as boron, silicon, iron, and other elements, may force these gases through fissures and porous areas in the surrounding rock where they frequently combine to form new minerals. Metamorphism of this type is called *pneumatolysis.* Many valuable ore deposits are formed by this method, among which are copper and tungsten.

Some of the gem minerals resulting from metamorphism, are:

- ANDALUSITE
- BENITOITE
- BERYL
- CHRYSOBERYL
- CORUNDUM
- EPIDOTE
- FELDSPAR
- GARNET
- IDOCRASE
- JADE
- KYANITE
- LAPIS LAZULI
- MARBLE
- PYRITE
- QUARTZ
- SERPENTINE
- SODALITE
- SPINEL
- TOPAZ
- TOURMALINE
- VARISCITE
- ZIRCON

A Geologic Cycle

From the facts given about the igneous, sedimentary, and metamorphic origin of minerals and rocks, we may assume that a sort of cycle of activity exists. Rocks or minerals of igneous origin are weathered away, to become part of a sedimentary formation, which may then be altered by metamorphism to another mineral or rock, which, perhaps much later, may be overtaken by an igneous activity and become part of a magma, to be later deposited and solidified into an igneous rock. This is where we came in.

It is believed by some authorities that certain parts of the earth's surface have completed three or more such cycles, and certainly, if atomic bomb evolution continues, we may have more cycles to come.

We have assumed that igneous solids are the bases of all forms of rock. We cannot doubt that the forces of igneous activity, erosion, and metamorphism were extremely active during the few million years following the geologic year of 1, when the crust first formed on the surface of the nebulous ball of gas we now call Earth. Time has marched on for about six billion years (plus or minus a billion or so) since that geologic year 1. Of the many things that have happened, certainly an end result has been to make extremely interesting hunting for the modern rock hobbyist.

Chapter 4

Hardness, Toughness, Cleavage, and Fracture

It may seem that the subject of hardness could be covered adequately in a few cogent sentences. We could say, "Hardness is the resistance a stone offers to being scratched when the pointed fragment of another mineral is drawn across it without sufficient pressure to develop cleavage in those stones known to have easy cleavage," or "Hardness is resistance to scratching." The mineralogists define it as "scratchability."

Hardness is a large factor in the durability of a gem stone. On it depends the ability to resist wear. If the softer materials are used as gem stones, constant care must be exercised to protect them against ruin from scratches and pits, and mountings must be designed to provide protection.

In this matter of hardness, it seems strange that the hardest of all materials, the diamond, and that quite soft mineral, graphite, are both composed of the same chemical element, carbon. However, the wide difference in hardness is due to the different arrangement and spacing of the atoms in their structure. The hardness of any material depends solely upon the *kind of atoms* of which it is composed and the *closeness of their packing.*

For the purposes of gemology, the *Mohs Scale of Hardness* is used most commonly. In 1820, Mohs, an Austrian mineralogist, selected ten minerals of different hardness, with a suitable gap between, to make this hardness scale. It has been used and almost universally accepted by gemologists and mineralogists the world over.

MOHS SCALE OF HARDNESS

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

Fingernail	about 2½
Copper coin	about 3
Knife blade	about 5½
Window glass	about 5½
Steel file	6 to 7

This is not an exact scale with each mineral having the indicated numerical relation to the others in degree of hardness. It does not mean that calcite is three times the hardness of talc, or that diamond is 1/10 harder than corundum. It only means that each mineral will scratch those of a lower number and, in turn, will be scratched by those of a higher number. And, if sufficient force is used, minerals of the same hardness will scratch each other.

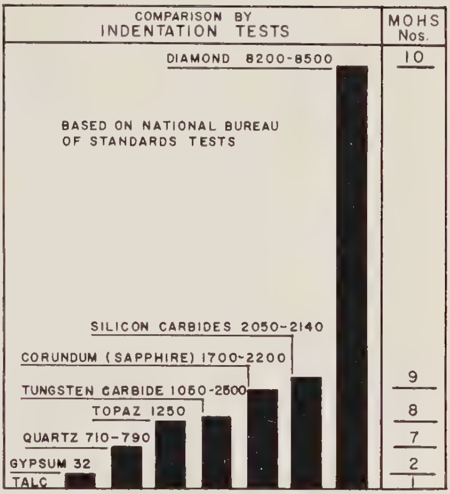
Many other hardness scales are in use to some extent and for specific purposes. The Brinell Scale, for instance, is used for metals and gives resistance to indentation rather than scratching.

A modern and more exact scale, but one not yet used in gemology, is that of the U. S. National Bureau of Standards, developed by the late Dr. Frederick Knoop. He used diamond points cut in the shape of an elongated pyramid. The scale was made on the basis of the *area* of the scratch resulting when the pyramid - pointed diamond was moved across the surface of the mineral with a definite weight applied and with a mechanically controlled movement.

Look at the comparison chart of the two scales, Mohs' and the National Bureau of Standards'. It is interesting to note how well Mohs selected the minerals on his scale up to his number 9, after which he had nothing to fill the wide gap to number 10, the diamond. Very few people appreciate the wide difference in hardness between the diamond and the next hardest mineral, corundum. Note particularly the difference in hardness between natural and synthetic sapphire, and the position on the scale of the modern, man-made abrasives, the carbides.

The question is often asked just where the dividing point between soft and hard stones comes. In the jewelry trade, number 7 and above are considered

OHS	BUREAU OF STANDARDS
1—TALC	(Not given)
2—GYPSUM	32
3—CALCITE	135
4—FLUORITE	163
5—APATITE	360 - 430
6—ORTHOCLASE	560
7—CRYSTALLINE QUARTZ	710 - 790
8—TOPAZ	1240 - 1300
9—SAPPHIRE, natural (corundum)	1400 - 1450
9—SAPPHIRE, synthetic	1650 - 2000
9—ALUNDUM (synthetic corundum, abrasive)	1620 - 1670
9⅛—TUNGSTEN CARBIDE (Carboloy)	1800 - 2000
9¼—BLACK SILICON CARBIDE (Crystolon and Carborundum	2050 - 2150
9¼—GREEN SILICON CARBIDE	2130 - 2140
9½—BORON CARBIDE (Norbide)	2250
0—DIAMOND	6200 - 6500



The chart above shows the relative hardness of various materials as determined by the National Bureau of Standards using the Knoop indenter described in the text. Data courtesy of Industrial Diamond Association of America.

ard, below 7 is soft. Quartz and harder ems are usually hard enough for ring ones. Gems below 7 are usually used nly for earrings, pins, etc. Women ften wear ring stones somewhat softer an men's, but they must give them xtra care.

Some exceptions to number 7 as a ividing point should be noted. Zircon, ½ in hardness, is somewhat brittle, robably due to the heat-treating pro-ess nearly all go through before cut-ng, and are quite prone to easy pitting the facet junctions. A zircon should ot be used in a man's ring.

Emerald, 7½ to 8 in hardness, al-ough rather hard and resistant to ratches, may fracture more readily an many other stones. It should al-ays be given extra care when used in ring.

Hardness As A Test

Hardness tests are quite satisfactory the mineralogist since he deals with ough materials, but the gemologist ould use hardness as a test only as a st resort. The reason, of course, is the er present possibility of injury to a ut stone.

In testing rough gem materials, the ardness test may often be the only test nmediately possible. Combined with facts easily noted on visual examination, such as evidence of cleavage, fracture, luster, etc., it may suffice for an identity.

Jewelers often use a broken file tip for a quick test on stones suspected of being glass. Most glass has a hardness of 5½, the file, 6 to 7.

Hardness testing is usually done with hardness points or hardness plates. The points are usually small metal tubes in one or both ends of which are cemented fragments of minerals of known hardness. Fragments of known minerals may also be held in the hand.

The material to be tested should be held firmly in one hand while the hardness point is placed in a flat spot on its surface. Pressure is applied to the point and it is slowly pulled back to make a scratch not to exceed one-sixteenth of an inch in length. The apparent mark that results should be wiped off to remove any residue. An examination can then be made with a hand lens to see whether an actual scratch has been made in the material being tested. If the point is the softer of the two, it will leave a streak or deposit of its own material. Successively harder points should be used until a scratch results on the material being tested.

When testing cut stones, the scratch

should be on the girdle or near the girdle on a back facet. *Never* test on the table or a top facet. Non-transparent cabochons with a rough back may be freely tested for hardness on the back.

Hardness Plates

Hardness plates are slices of minerals, on the Mohs Scale of Hardness, with a flat surface, not necessarily polished. The use of hardness plates rather than points for testing cut stones is strongly recommended.

The hardness plate is held firmly in the hand while the girdle of the stone is applied to the plate for the test. Testing in this manner, damage to the stone is unlikely to occur. However, no cut stone suspected of easy cleavage, such as topaz, spodumene, epidote, or sphalerite, should ever be subjected to *any* hardness test, or two stones instead of one may be the result.

With hardness points, the hardness is determined as the number *below* that of the point that will scratch the material. With hardness plates, the hardness is the number *above* that of the plate which the material will scratch.

Assessing the hardness of a stone requires some degree of judgment. Some stones have a varying hardness depending on inclusions and other factors as well as a variation in hardness with respect to different axial orientation. Kyanite is the classic example of material that varies with the orientation of the crystal in relation to the direction in which the hardness test is made. Parallel to the long direction of the crystal it has a hardness of 5 to 6. At right angles to this direction, the hardness is 6 to 7.

Before any hardness test is accepted as final, reference should be made to an accurate description of the material to determine any possible variation in hardness due to direction, orientation, or other factors.

Proper testing for hardness is not as easy as it sounds. Practice is recommended before testing good stones. A piece of ordinary glass is 5½ in hardness and will make a good hardness plate for practice. After considerable testing, one can tell the approximate hardness from the way the harder material "bites" into the glass and the ease with which it makes the scratch.

To the gemologist, a knowledge of the hardness of gem stones is useful for purposes other than testing. The harder stones will usually take the best polish, retain it the longest, and may be used to best advantage in jewelry. The diamond owes much of its beauty to its ability to take a high polish and to its adamantine luster, both the result of its superior hardness.

Toughness

Toughness is the resistance a stone offers to breakage or cleavage when subjected to blows, pressure, or heat.

Hardness and toughness are the two important properties upon which a gem stone's durability rests. A stone must be hard to resist wear and retain its polish and brilliance, but if it becomes worn or scratched it can be repolished. If a stone lacks toughness, it may fracture or cleave, and for this there is no repair.

Many minerals would be listed among our more valuable gem stones were it not for the fact that even light pressures or blows will cause them to break or crumble easily.

Do not confuse the properties of toughness and hardness. A stone may be quite hard and still not have the toughness of some stones of much lower hardness. A good example is nephrite jade. It has a hardness of only 6 to 6½ but, because of its fibrous structure, it is rated high on a scale of toughness well above such hard minerals as topaz spinel, and zircon. Nephrite is therefore a very durable gem stone. Another example of tough material is rubber Quite soft, it may be dented with the finger, but, because it strongly resists separation, it is classed as a tough material.

The scale of toughness given below is a composite of several authorities modified by our own experience in gem cutting:

Carbonado, a non-gem variety of diamond, placed at 10 on the scale, is a crystalline aggregate and probably the world's hardest and toughest material Carbonado, at present found only in Brazil, is scarce and commands high rices as an industrial diamond.

Only heat-treated zircon is listed as eldom, indeed, does one find the untreated mineral on the market, cut or ough. The report is that all zircon is eat-treated once or twice at the mines o modify the colors to blue or colorless. Untreated zircon, supposedly, ould be at least one point higher on e scale of toughness.

Cleavage

Cleavage is the tendency of certain rystals to separate between weak atom lanes that are parallel to some possible rystal face. Separation through cleavage results in smooth surfaces, although ometimes with distortion due to the rystal form.

The ease with which crystals separate classed as follows; *perfect, distinct, ndistinct* or *imperfect, difficult or poor,* nd *none.*

Cleavage directions are described by e crystal face along which they separate, such as:

Octahedral cleavage. Cleaving parallel the faces of the octahedron. Examples, diamond and fluorite.

Rhombohedral cleavage. Calcite.

Basal cleavage. Cleaving parallel to e base of the crystal. Topaz and beryl.

Dodecahedral cleavage. Sphalerite.

Cubic cleavage. Galena and halite.

Prismatic cleavage. Cleaving lengthwise of the crystal. Nephelite.

Somewhat similar to cleavage is a roperty known as *parting,* often called false cleavage." This is not a true leavage but a separation along a *twinning plane* between the parts of a twinned crystal. Corundum and diamond are the only gem minerals in which parting is a notable factor.

In rough gem minerals cleavage plays an important role in identification as a certain type of cleavage or a lack of cleavage, noted in or on the surface of the specimen. An example would be water-worn pieces of colorless topaz and quartz. Topaz has basal cleavage that is highly perfect and no matter how smoothly worn the surface, topaz will show small points of cleavage, often giving a sort of glistening appearance. Quartz, having no cleavage, will show nothing of this kind.

Cleavage is of less importance in the identification of cut stones, but occasionally, when a gem is examined under magnification, indications of internal cleavage planes are apparent and may aid in determining the identity.

Cleavage is very important to a gem cutter. Knowing the direction of cleavage often means the difference between a valuable finished faceted gem and one that was ruined when it split during the faceting procedure.

Minerals known to be easily cleaved should not be cut with the table parallel to the direction of cleavage. Lapidaries usually orient the stone so the table will be 5 to 15 degrees off the cleavage direction. Also, polishing may be difficult or impossible directly parallel to the plane of easy cleavage.

Cleavage is often used by gem cutters to reduce the size of rough material. If an easily cleaved mineral is too large, its size may be reduced by cleaving rather than using the slower method of sawing. Or if it has undesirable portions, they may be removed by cleaving.

Gem materials in which the atoms are in a random orientation rather than in exact geometrical form as in crystals, are termed *amorphous.* Such materials not having any true atom planes cannot be cleaved. Examples are opal, glass, and plastics. *Amorphous materials never have cleavage.*

Fracture

Fracture is the breaking or chipping of a substance in any direction other than along a cleavage or parting plane. For example, we can split a piece of

SCALE OF TOUGHNESS

arbonado	10	Topaz	5
ephrite or Jadeite (jade)	8	Orthoclase	5
orundum (ruby, apphire)	8	Labradorite (transparent)	5
uartz	7½	Labradorite (opaque)	4
iamond	7½	Amber	3½
halcedony	7	Apatite	3½
eryl (other than emerald	6½	Sphene	3½
eridot	6	Spodumene	3
eryl (emerald)	5½	Euclase	3
arnet	5-6	Epidote	2½
ircon (heat reated)	5	Proustite	2½

wood along its grain and compare this with the property of cleavage. But if the same piece of wood is broken *across the grain,* we can compare this with the property of *fracture.*

The terms used by gemologists to describe the various types of fractures are:

Conchoidal. The commonest of fractures, a curved, shell-like type, common to most gem minerals, especially noticeable in glass and obsidian. The fractured surface often has curved ridges like ripples on water or the outside markings of a shell.

Splintery or fibrous. When the break shows a splintery or fibrous grainy effect. Examples are tigereye and hematite.

Granular. Typical of crystalline aggregates, somewhat like the appearance of a broken lump of sugar.

Uneven. An irregular or somewhat jagged break. Pearl, coral, jasper.

Even. Almost approaches, but not quite, the smooth appearance of a cleavage plane.

As in cleavage, fractures play a part in identification of some gem stones. The type of fracture and the luster on its surface may help in eliminating certain varieties. They are a help in identifying cabochons more often than faceted stones. Fractures are not always seen on faceted stones, but cabochons, new or old, are seldom without a few tiny fractures along the girdle, although some magnification may be necessary to see them.

For example, if a translucent, milky cabochon is being examined, the possibilities are threefold: true moonstone, chalcedony moonstone, or glass. Even a very small break on the girdle will be sufficient to decide which one it is. If the stone is chalcedony moonstone, the fracture will be conchoidal and the luster on the fractured surface will be dull or waxy. If the stone is glass, the fracture will also be conchoidal but its luster will be very bright, said to be glasslike or vitreous. If the stone is true moonstone, a variety of orthoclase feldspar, there will be no conchoidal fracture but perhaps a series of tiny breaks showing cleavage planes. Thus the identity can be established through the type of fracture by using a hand lens or microscope.

Cohesion

We have spoken of hardness and said it is the result of the kind of atoms and the closeness of their packing. We have said that cleavage is the splitting of a material between the most widely spaced rows or planes of atoms. Some readers may wonder how atoms can form in planes so widely spaced and not fall apart. What holds atoms together so that matter maintains its form? That is certainly a good question.

Atoms are held together by the same force that holds our planets in their orbits around the sun and, for want of a better name, we call this force *cohesion.*

This force or attraction between all bodies of matter, large or small, can best be described as a *balancing of forces.* Upon it, all matter depends for its existence. It is said that atoms lie close together yet not actually touching, held together and maintained in position by the force called cohesion.

Just what does cohesion have to do with gemology? The same might be asked about many of the abstract terms used in the science. Let us briefly review a few of these terms. Cleavage is a separation between atom planes. Toughness is resistance to cleavage. Cohesion is the force causing toughness or resistance to cleaving, the force tending to maintain the atoms in their positions. So, to cleave a mineral, a force must be used, a force sufficient to overcome the cohesion between the atoms. The greater the separation between atom planes, the less the force necessary to separate them.

Some Other Physical Properties

A few minor mineralogical properties are explained below. These terms are frequently used by mineralogists, but although infrequently used, should be understood by gemologists.

Malleability. The property of minerals permitting them to be flattened out under blows without crumbling. The only truly malleable minerals are the native metals. Gold is the best example.

Ductility. A term applied to ma

erials which can be changed in shape y pressure or drawn into the form of ire. Examples—gold, silver, copper.

Sectility. If a material can be sliced, r a shaving turned up with a knife, it said to be sectile. Cerargyrite (horn ilver) is an example.

Flexibility. Applies to a mineral hich may be bent easily and stays bent hen pressure is removed. Example, an-ealed copper, or talc in thin laminae.

Elasticity. The property of minerals hich allows them to be bent or pulled ut of shape but return to their original orm or position when force is removed. xamples, plates of mica.

Brittleness. Minerals which crumble into fragments under blows, pressure, or when cut with a knife, are termed brittle. All gem minerals are considered brittle, differing only in degree.

Even diamonds are considered brittle and are quite easily cleaved if the strain is applied in exactly the direction of easy cleavage. However, diamonds are well up on the scale of toughness, though their toughness can be greatly lowered if internal strain is present. Such strain can be caused by irregularities in the crystal structure or excessive inclusions.

HOW TO PRONOUNCE GEM AND MINERAL NAMES

ronunciations given here are according to the best authorities available and are generally ccepted by mineralogists, gemologists and geologists. Where no mineralogical or gem-logical authority was available, Merriam-Webster **New International Dictionary,** un-bridged, (1956) has been taken as the authority.

LMANDITE—AL-man-dite (never al-MAN-dite)
MBLYGONITE—am-BLIG-oh-nite
NALCITE—an-AL-cite
PATITE—AP-a-tite
VENTURINE—a-VEN-tchu-rin (rhymes with adventure in)
AUXITE—BO-zite
ERYL—BER-il (to sound like burial with the "i" omitted. Never "burl")
ERYLLONITE—bear-IL-o-nite
RECCIA—BRECH-ee-ah
ALCITE—KAL-site
AIRNGORM—KAYRN-gorm
ARNELIAN—kar-NEEL-yon (in England, frequently spelled cornelian but pronounced the same)
ELESTITE—SEL-es-tite
ITRINE—SIT-reen
HRYSOBERYL—KRIS-o-bear-il
HRYSOLITE—KRIS-o-lite
HRYSOPRASE—KRIS-o-prase (rhymes with praise)
HRYSOCOLLA—kris-o-KOL-a (rhymes with Coca Cola
HALCEDONY—kal-SED-o-nee
HIASTOLITE—ki-AS-toe-lite (first syllable rhymes with eye)
CROCIDOLITE—kro-SID-o-lite
CUPRITE—KOO-prite
DANBURITE—DAN-bur-ite
DEMANTOID—de-MAN-toid (rhymes with Lloyd)
ELAEOLITE—e-LEE-o-lite
GNEISS—NICE (rhymes with lice)
GOETHITE—GER-tite (first syllable rhymes with the "gert" in Gerty with most of the "r" sound left out)
GROSSULARITE—GROS-u-ler-ite
HELIOTROPE—HEE-lee-o-trope (rhymes with rope)
HEMATITE—HEM-a-tite ("Hem" like the hem of a dress)
HYACINTH—HIGH-a-sinth
HYALITE—HIGH-a-lite
IDOCRASE—EYE-do-krase (rhymes with days)
INDICOLITE—in-DICK-o-lite
IOLITE—EYE-o-lite
KAOLIN—KAY-o-lin (rhymes with shin)
KORNERUPINE—kor-ner-OO-pin (rhymes with "you pin")
KYANITE or CYANITE—KY-a-nite
LABRADORITE—LAB-ra-do-rite
LAPIS LAZULI—LAP-is LAZH-u-lie (rhymes with pie) or LAZH-u-lee (rhymes with see)
MALACHITE—MAL-a-kite
NEPHRITE—NEF-rite (first syllable rhymes with Jeff)
NEPHELITE—NEF-uh-lite
OOLITE—OH-oh-lite (rhymes with jo-jo-might)
OLIGOCLASE—AHL-i-go-klaze (the "i" like in sit)
PERIDOT—PAIR-i-doh (like go) or PAIR-i-dot (like tot). The first is more frequently used by gemologists.
PERIDOTITE—PAIR-i-doh-tite or pair-RID-o-tite
PHENAKITE or PHENACITE—FEN-a-kite or FEN-a-site
PLAGIOCLASE—PLAY-jo-klase
PREHNITE—PRAY-nite
PSILOMELANE—si-LOM-e-lane (the "i" like eye)
RHODOCHROSITE—ro-do-KROW-site (all "o's" rhyme with go)
RUTILE—RU-teel
SPINEL—spi-NEL
SPHALERITE—SFAL-er-ite (first syllable rhymes with Cal)
SPHENE-SFEEN (rhymes with sheen)
SPODUMENE—SPOD-u-meen (usually sounds like SPODJ-u-meen)
TRAVERTINE—TRAV-er-teen
UVAROVITE—oo-VAR-oh-vite (first syllable rhymes with two)
ZINCITE—ZING-kite

Chapter 5

The Weight of Gems

Specific Gravity, Sp.Gr., SG, is an important and extremely useful property in gem identification. Often spoken of as the *density* of a material, it represents the *relative* density of a material when compared with water. Therefore, SG is really a *ratio* and not a weight.

This is a fact frequently required in gemological examinations. For example, the SG of gold is 19.4. If a certain quantity of water weighs 1 ounce, the same quantity of gold weighs 19.4 ounces. Also, the SG of diamond is 3.52 and it is, therefore, 3.52 times denser than water.

The discoverer of the principle of specific gravity was the famous Greek mathematician, Archimedes. In the year 224 B.C., King Hiero of Syracuse had a gold crown made for himself. Wanting to be sure it was pure gold and not an alloy, he gave it to Archimedes with orders to test it, but forbade him to deface or mar it in any way. As can be imagined, a very puzzled Archimedes tried hard to find out what the crown was made of.

No ordinary test could be applied without disfiguring the crown. But when at his wit's end and while in his bath one day, lo and behold, our hero noticed the increased buoyancy of his body as it sank into the water. He decided that very principle could be used to solve his problem. He is said to have jumped out of the bath and run through the streets shouting, "Eureka! Eureka!" (I have found it.)

He reasoned that the buoyant force of the water on his body was equal to the *weight of the water it displaced.* And so (we hope), he lived happily ever after. It is said that upon testing the King's crown, Archimedes found it to be heavily alloyed. We cannot help but wonder whether the maker of the crown lived happily ever after.

But the principle of Archimedes, that a body immersed in water loses as much weight as the weight of the water it displaces, is as useful today as it was in 224 B.C.

If we open a modern dictionary to *specific gravity* and read, "Specific gravity is the ratio of the weight of a body to that of an equal volume of a standard substance, water in the case of solids and liquids, air or hydrogen in the case of gases; numerically equal to its density," we might worry about how this could be practically applied to gem testing. But if we merely ask how much heavier is this gemstone than the amount of water it will displace, we put it on a more understandable basis.

Each gem mineral, if composed of the pure elements intended by Mother Nature to make up that mineral, will have a stable and definite specific gravity. However, impurities in minerals may cause variations which we must bear in mind. The color in most gems is caused by impurities, so the depth of color alone can cause a variation in specific gravity.

The species corundum, with its varieties ruby and sapphire, has an SG of 4.0, which means that each stone will weigh four times as much as the water it will displace. But how can we find the exact weight of the water it displaces?

Hydrostatic Method

The best known method of doing this is called *hydrostatic method.* Its first application is very simple if we have a good balance (scale). First, we weigh the specimen very carefully and write down the weight. This is called the *weight in air.*

Next, we weigh it while freely suspended in water, knowing that the water will push up on the specimen an amount exactly equal to the weight of water displaced. It will therefore weigh as much less while suspended in water as the displaced water weighs. This is the *weight in water.*

As an example we can use the corundum mentioned above. If we have a pecimen which in air weighs exactly 12 arats, and in water was found to weigh carats, the difference between these eights would be the weight of the ater displaced, or the amount the water ushed up on the specimen. Subtract 9 rom 12; the difference, 3 carats, is the eight of the water displaced. Now, nce specific gravity is a ratio between he specimen and the water, dividing the eight of the specimen by the weight of he water displaced will give that ratio; 2 divided by 3 equals 4.0, which is the G of corundum.

The equation is:

$$\frac{\text{Wt. of the stone in air}}{\text{Wt. in air, less wt. in water}} = \text{S.G.}$$

$$\frac{12\ (\text{wt. in air})}{12\ (\text{wt. in air}) - 9\ (\text{wt. in water})} =$$

$$\frac{12}{3} = 4 = \text{S.G.}$$

Another factor must be mentioned. his is water temperature. Water at 4 egrees centigrade (about 39 degrees F) taken as SG 1.0 or unity. At this temperature water has maximum density nd, technically, comparisons in density hould be made with water at this temperature. However, if water rises to a oom temperature of, say, 70°F, its ensity will drop only about .002. The ctual density of the water would then e .998 instead of 1.0. We could term his .998 a correction factor by which multiply the previous answer of 4.0. his would give an *unnecessarily* (for emological purposes) accurate SG of .992.

The above temperature correction is n inconsiderate factor and should not e used in normal gemological testing. is mentioned principally to bring out he method of using a correction factor any liquid other than water is used n which to weigh the specimen.

The surface tension of water is rather onsiderable. For accurate SG testing f stones under one-half carat, a liquid f low surface tension should be used. arbon tetrachloride has been used for his purpose. Its SG is 1.59, so this gure is the correction factor by which multiply the answer obtained by the regular formula if carbon tetrachloride is used as the liquid.

Instead of using carbon tetrachloride, the modern and more popular method is to add a small amount of detergent to the water. A very small amount of the Kodak wetting agent, *Photo-flo,* or a little of any good detergent type washing powder or liquid answers the purpose very well. No correction factor is necessary when a detergent is added to the water.

If a correction factor is used, the equation is:

$$\frac{Wa}{Wa - Wl} \times CF = SG$$

Wa - weight in air
Wl - weight in liquid
CF - correction factor
SG - specific gravity

The equipment to make satisfactory SG tests of ordinary gem stones encountered in the jewelry trade usually consists of some form of diamond weighing balance specially equipped for SG tests. Costs of diamond balances vary from about $100.00 to $800.00, which seems rather prohibitive for amateur gemologists. The smaller hand balances, familiar to many, costing $20.00 to $50.00, can be easily rigged for SG testing with a slight loss in accuracy. For larger stones of about 5 carats (1 gram) up to 1 or 2 ounces, photo or darkroom scales, such as that made by Eastman Kodak Company, can be fitted for SG testing. They are not sufficiently sensitive for small gems.

Details for fitting up and using such equipment will be given later along with details of other equipment, more or less easily homemade.

Heavy Liquids

The use of heavy liquids for specific gravity testing has both advantages and disadvantages. Advantages are cheapness, convenience and speed, portability, and the decided advantage that stones, however small, may be tested by the sink or float method. (Testing stones smaller than one-half carat by hydrostatic methods is usually inaccurate. The disadvantage of heavy liquids is that the test does not give a definite SG. It indicates only the fact that the specimen is lighter or heavier than the liquid.

Any fluid having a greater density than water might be termed a heavy liquid. However, certain things are necessary to make such fluids suitable for gem testing. By describing them as denser than water, we mean they have a higher SG and weigh more per unit of volume than water. Viscosity or thickness does not appear as a factor. A liquid may be of noticeably higher viscosity than water and yet be of lower density. Ordinary motor oil is an example of this. Much higher than water in viscosity, it floats readily on water.

All gems, whether of mineral or other origin, are in the SG range between 1.08 (amber) and 7.0 (cassiterite). However, the commoner varieties of gems fall within the range of 2.10 (opal) and 4.70 (zircon).

The two commonest heavy liquids used in gemology are bromoform, SG 2.90, and methylene iodide, SG 3.32. Either may be diluted with xylene to any desired lower specific gravity.

Several years ago the Gemological Institute of America decided upon the three most useful and easily obtained densities for these liquids. Time has proven how wise that choice was.

First, methylene iodide, the most expensive of these liquids, is used undiluted, SG 3.30 or 3.32. Second, bromoform, undiluted, SG 2.89 or 2.90. Third, bromoform diluted with xylene to a density of 2.62. Sets of these three liquids, an ounce or two of each in neat, wide-mouthed bottles, can be purchased from the Gemological Institute. Also the liquids may be obtained from wholesale drug suppliers but are quite expensive.

Instead of bromoform, the authors use acetylene tetrabromide, SG 2.96. This is diluted to SG 2.90 and 2.62 with xylene. It has certain advantages that will be mentioned later.

Other less frequently used liquids are, monobromonapthalene, SG 1.49; carbon tetrachloride, SG 1.59; a saturate solution of table salt, SG 1.15; and Clerici solution, SG 4.20, but usually diluted with distilled water to SG 4.0.

Clerici solution, a 50-50 mixture of thallium formate and thallium malonate, is quite poisonous and highly corrosive. It is the most difficult to get and by far the most expensive of the heavy liquids.

The actual use of heavy liquids for SG testing is simple. The stone is dropped into the liquid. If it sinks it is higher in SG than the liquid. If it floats, it is lower in SG. With a little practice one can estimate rather closely the SG of the stone by noting how fast it sinks or how rapidly it rises after being dunked to the bottom of the bottle with a pair of tweezers.

To be of maximum usefulness, heavy liquids should be transparent or as nearly so as possible. A series of heavy liquids of the suspension type, rather inexpensive, are often advertised. They are available from about SG 3.0 to SG 7.5. They would be ideal, and I am sure would be used by all gemologists, except for the fact that they are completely opaque! Another liquid made by this firm is adjusted to SG 3.52 and is intended for checking diamonds. A diamond will just float, or remain suspended in the liquid, while zircon will sink rapidly. The bad part of using this solution is the extreme difficulty in cleaning the stone after removing it from the solution. One jeweler told me he had to boil his diamonds in acid to remove the SG solution. So if you buy heavy liquids be sure they are suitable for gem testing.

Later we will tell you more about the practical details of using the SG balance, how to mix and use the heavy liquids, where to buy them, and how to care for them.

hapter 6

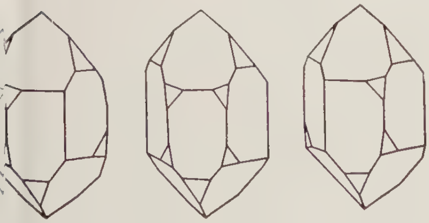
rystals as Gems

We hestitated to use the word *crystal-graphy* for the heading of this chapter, r the subject is a deep one, and the me may frighten away those wishing avoid a highly technical subject. What e hope to present is a minimum of chnicalities and big words, and yet clude all of the necessary informa-on about crystals and their relation gemology.

Just what is a crystal? Dana says, "A ystal is a homogeneous body bounded plane surfaces that are an external pression of an orderly internal atomic rangement." Therefore, to be a crys-l (noun), an object must have an derly atomic arrangement *and ex-rnal faces.* There seems to be some ndency to use the word *crystal* as an ljective to indicate a material with a finite atomic arrangement but no ces. The word *crystalline* would be ore appropriate in such cases.

Of course, neither the word *crystal* r *crystalline* should ever be applied to glass material such as glassware or ass beads. Some jewelers incorrectly ply the term "crystal ware" to finer ality glass dishes. Materials such as ass and plastics, having a random ar-ngement of atoms, are said to be *orphous,* meaning "without form."

Materials without external evidence of internal crystalline structure are rmed *massive.* They may or may not be crystalline, but if there is no external evidence of a crystalline nature, they are massive. When applied to minerals, the word has no reference to size or weight.



6-1. Twinning of right- and left-hand artz crystals according to the Brazilian w. At the extremes are single crystals, the nter is the twinned crystal containing the ces of both right and left hand individuals.

When crystals are grouped together they form an *aggregate.* If the individual crystals are medium to large, let us say large enough to be cut into gem stones, the group is called a *crystal aggregate.* If the crystals grouped together are smaller, barely visible to the unaided eye or visible with some degree of magnification, they are called a *crystalline aggregate.* The metals whether formed or in their native state, are crystalline aggregates. Gold, silver, and copper are examples.

Crystalline aggregates are divided into *fibrous* and *granular* types. Fibrous crystals are often long and needlelike. Examples are: satin spar, asbestos, and tigereye.

Granular aggregates are of two general types. *Phanero,* or distinctly crystalline aggregates, are of the type wherein the individual crystals can be seen, with perhaps some degree of magnification. Examples are granite and lapis lazuli.

Cryptocrystalline, or minutely crystalline aggregates, are made up of materials and crystals so small that the individual crystals cannot be seen even with high magnification. They have been proven to be of crystalline nature by polarized light and petrographic methods. Agate and other varieties of chalcedony are cryptocrystalline.

Crystals may grow together in the form of twins. When two crystals are joined together along a common axis or plane, it is called a *twinned crystal.* Fig. 6-1. When two crystals are joined together along a common plane, it is called a *contact twin.* Fig. 6-2. If each crystal of the joined pair is a mirror image of the other, it is called a *macle* or *spinel twin.* Fig. 6-2. Spinel and diamond often twin in this manner.

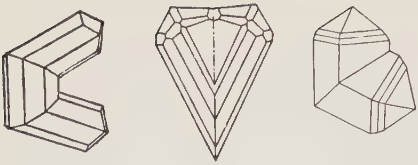


Fig. 6-2. Left and center, forms of contact twinning of rutile. At the right, a common form of twinning in zircon.

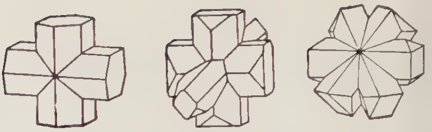


Fig. 6-3. These sketches show two forms of penetration twinning in staurolite (left and center and repeat twinning in staurolite. All sketches after Dana's textbook.

When the crystals appear to be intergrown and parts of each crystal appear to be occupying the same space as similar parts of the other crystal, it is called a *penetration twin.* Staurolite "fairy crosses" are penetration twins. Fig. 6-3.

Repeated twinning is the name applied where three or more individuals are twinned in the same way. When several twinned crystals are flat, and the planes of junction are parallel, it is called *polysynthetic twinning.* Feldspar is an example, with albite, microcline, and labradorite frequently twinned in this manner.

Another type of repeated twinning is the *cyclic twin.* In this type, the junction planes of the crystals are not parallel, but appear as successive wedges in a cut pie, often making what appears to be a hexagonal crystal. Chrysoberyl and witherite often twin in this manner, and are called *pseudohexagonal.* Fig. 6-4.

Twinning in most of the above types is of such nature that the resultant twinned crystal is still satisfactory for cutting. Separation along a twinning plane, or *parting,* is not common. Twinning planes are seldom visible after the stone is cut. This is not true for the type of polysynthetic twinning in mica and some other minerals. The separation between certain planes of atoms in this type is much greater and results in easy splitting of the crystals, which are in thin sections or layers. This is called *foliation* or *lamination,* and the thin plates are *laminae.* Such minerals are quite unsuitable for cutting.

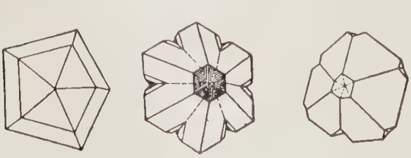


Fig. 6-4. Repeat twinning with each individual reversed. Such twinning frequently yields a pseudo-hexagonal or octagonal appearance. The left sketch is a twinned spinel, the center chrysoberyl, and the right, marcasite.

A useful list of the commoner terms applied to the appearance or habit of crystals or crystalline aggregates will be found in the appendix.

False Fronts

We now come to pseudomorphs, paramorphs, and polymorphs. Don't go away, they are easy to understand, even if they sound tough.

When a mineral is altered so that the structure is changed but the external form is preserved, it is called a *pseudomorph,* which means "false form." Pyrite, an iron sulfite, may under some conditions alter to iron oxide to form limonite while retaining the perfect form of the pyrite crystals. This is spoken of as "limonite *after* pyrite."

Another pseudomorph, more familiar to rockhounds, is petrified wood in which the fibers have been replaced by silica. This is called the substitution method because there is no chemical reaction or alteration between the wood and the replacing silica. Another pseudomorph of this type is crystalline quartz after fluorite.

Pseudomorphs are also formed by incrustation when one mineral is deposited over the crystals of another. Quartz may incrust cubes of fluorite and the fluorite later be removed by solution.

When the chemical of which a crystal is composed changes its crystalline character without altering its external form, it is called a *paramorph.* Two well known examples are aragonite (orthorhombic) altering to calcite (hexagonal); and rutile (tetragonal) to brookite (orthorhombic), each keeping its original exterior crystal form though ltering its internal atomic structure.

If the same chemical substance occurs n two or more different crystal types, t is called a *polymorph*. Carbon is an xample. It exists in the form of dianond and graphite, each with widely liffering properties and each occurring n a different crystal system.

The Crystal Systems

We will now tell you about the six rystal systems, together with the necesary facts about the relative length and ngular relation of their axes. We will xplain why it is advisable to gain t least this elementary knowledge of rystals.

A very large percentage of gem maerials are of crystalline nature and an nderstanding of the nature of crystals vill help to acquire a better understandng of both the physical and optical roperties of the gems one works with.

There are six crystal systems and all rystalline materials must, of necessity, rystallize in one of these systems. Due the shape and size of the atoms and e way they are grouped together, each ystem has its own peculiarities, its own articular degree of symmetry or lack f it. These are the peculiarities of strucure which identify each system, making different from the others.

So that we may discuss crystals more asily, we will explain a few of the decriptive terms applying to them.

Crystals, being made up of geometrially arranged rows and planes of atoms, re usually bounded by somewhat mooth surfaces called *faces*. A random ut facet on a crystal is not a face. rystal faces are an expression of the nternal structure.

Any directions of cleavage a crystal ay have are parallel to a crystal face r are along a direction where a crystal ce might have formed.

The angles between similar faces of a ystal of any particular species will alays be the same whether the crystal as grown in San Diego County or in ladagascar, whether the crystals are rge or small, nearly ideal or distorted, hether grown by nature or in man's boratories. However, this does not old if the crystals have been deformed y external forces *after* they are grown.

This *constancy of interfacial angles* among crystals of the same species (that have not been deformed or badly distorted) is one of the most reliable methods of identification. Very exact methods have been developed for measuring these angles. However, the method is seldom used in gemology since most identification is done on cut gems.

Crystal symmetry — this rather technical sounding term is used to express the recurrence or repetition of faces and edges on a crystal. Symmetry is a most important subject in mineralogy and is of definite interest in gemology. It is suggested that, for the purpose of gemology, our description or explanation of kinds and degrees of symmetry be read and understood but not memorized. However, a nominal understanding of planes and axes of symmetry is necessary so that we may create a mental image of a crystal from a printed or oral description.

Axes of Symmetry

An imaginary line passing through the center of a crystal about which it can be revolved so that similar faces recur a certain number of times during a complete revolution is called an *axis of symmetry*. According to the shape of the crystal, it may exactly repeat itself two, three, four, or six times during a complete revolution. These axes are spoken of as axes or directions of 2-fold, 3-fold, 4-fold, or 6-fold symmetry.

Consider the cube as an example. A cube has three axes of 4-fold symmetry which pass through the center of each face; four axes of 3-fold symmetry passing through the cube from corner to corner; also six axes of 2-fold symmetry, which pass through the center of each edge. Each axis must pass through the center of the crystal. Figs. 6-5, 6-6, and 6-7.

To understand this fully, one should have a model. Find a cube-shaped box, or paste one up from paper or cardboard, or cut a cube from a raw potato. (See illustrations.) Use a knitting needle or a stiff wire of proper size for the axis. Poke holes and pass the wire through the box in each postition mentioned above. Verify the number of

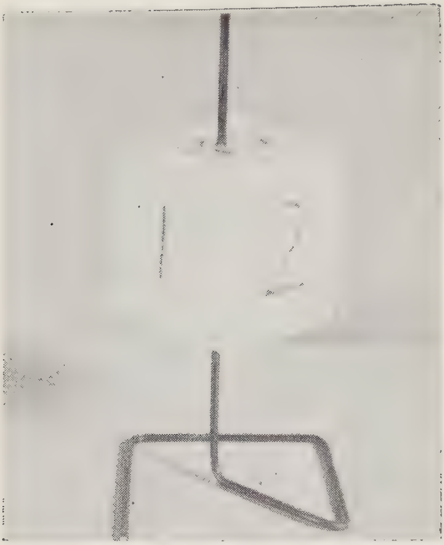


Fig. 6-5. This shows the axis of symmetry that goes through the middle of two sides of a cube. As there are six sides, there are three possible directions that the axes can take. As there are four positions in which the cube can be placed, by rotation, around the axis, where it appears exactly similar, the cube is said to have three axes of four-fold symmetry.

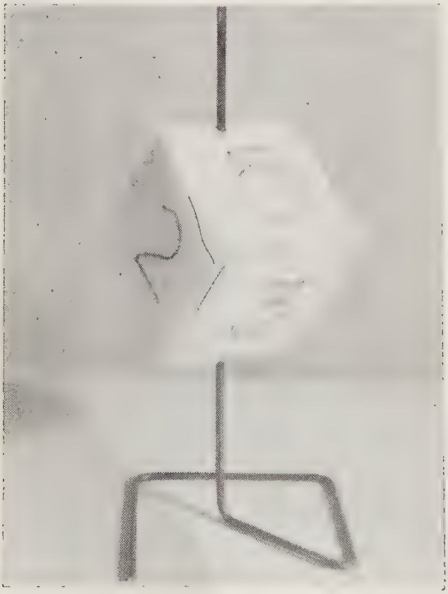


Fig. 6-7. The axis in this cube goes through the center of opposite edges. As there are 12 edges on a cube, there are six possible positions that the axis can take. In this case, there are only two positions to which the cube can be oriented where it looks exactly the same. The cube, then, also has six axes of two-fold symmetry.

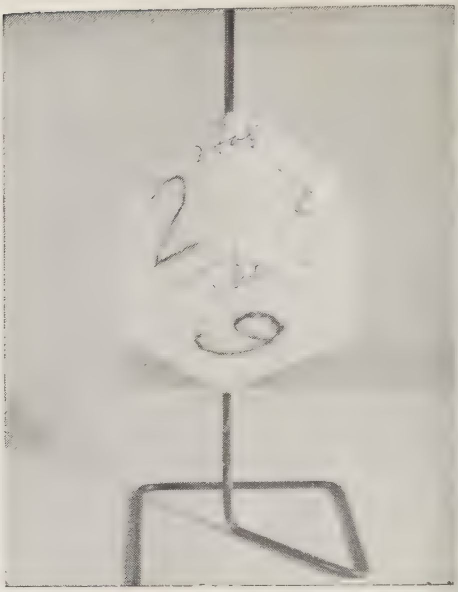


Fig. 6-6. Here the axis of symmetry of the cube goes through it from corner to corner. As there are eight corners on a cube, there are four possible directions that the axis can take. By rotating around the axis, there are three positions in which the cube will appear exactly the same to the eye. The cube therefore has four axes of three-fold symmetry.

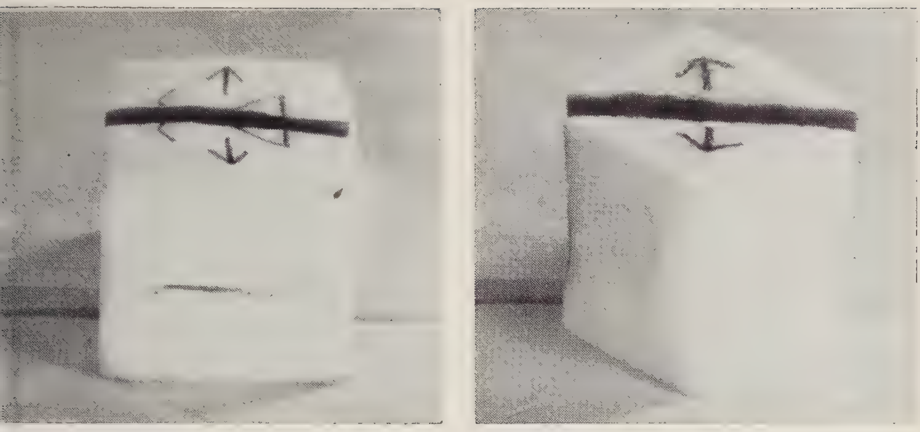
axes and count the positions of symmetry of each axis as the cube is rotated. This will fix the matter of axes of symmetry in the mind.

A plane that divides a crystal into two parts, exactly similar faces occurring on each side so that each half is a mirror image of the other, is called a *plane of symmetry*. Each face, edge, or angle must have an exact counterpart on the other side of the plane.

A cube has nine planes of symmetry along which it may be divided, with each half being an exact counterpart of the other. From Figs. 6-8 and 6-9 try to find and mark them on your axes model.

Names of Crystal Systems

So far we have not suggested much memorization, but there are a few points or bits of data in gemology that should be memorized. We suggest that all who are sufficiently interested in gemology to read these lessons twice, memorize the names of the crystal systems and the relative lengths and angular relations of their axes. Try to get a mental picture



igs. 6-8 and 6-9. These two pictures show two of the planes on which a cube can e divided so that the two halves, if placed in front of a mirror (as these have been), vill appear exactly similar but be "mirror" images. These are planes of symmetry. There re nine different planes, either from edge to edge (as the right hand picture) or from ore to corner (as in the left), along which a cube can be cut. There are, therefore, ine possible planes of symmetry in a cube. See DANA'S TEXTBOOK OF MINERALOGY, age 11, for a drawing of all possible planes.

f an ideal crystal in each system or nake a potato model of each.

Ideal crystals are not made by nature r by man. They come only from the rafting board, the model-makers bench, r the imagination. It has been said that ature never exactly duplicates anything, o if she ever made an ideal crystal, she vould have made only one.

But nature, through long practice in rystal construction and, perhaps, beause of the affinity of certain atoms for ach other, has formed certain habits of onstruction that help greatly in identiying crystals. These habits of construcion have been grouped into what we all the *six crystal systems.*

In learning the names of the crystal ystems, the sequence given should be ollowed. To the mineralogist, this is a equence of decreasing symmetry. But to he gemologist the reason for following his sequence is one of simplification and to make easier the memorization of the optic character of the minerals in each system. Learning them in this sequence will save time and mental effort. It is difficult for some beginners to remember which systems are singly refractive, which doubly refractive, which uniaxial, and which biaxial. Write and memorize them as given in the table below.

The first *one* is singly refractive, all others doubly refractive. The next *two* are uniaxial. The last *three* are biaxial. Simple? Sure. Simple as 1 - 2 - 3.

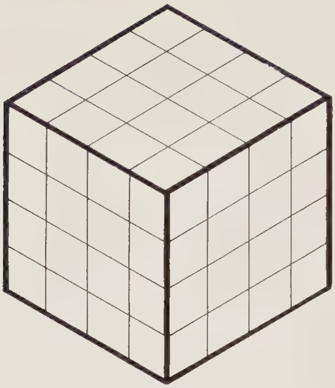
The terms, single refraction, double refraction, uniaxial, and biaxial, will be fully explained in the chapter on optical properties.

In the following brief discussions of each crystal system, the parts to memorize are in italics. Of the gem minerals mentioned as crystallizing in each system, the more important are in italics. These may be memorized later if desired.

YSTEM

. CUBIC
. TETRAGONAL
. HEXAGONAL
. ORTHORHOMBIC
. MONOCLINIC
. TRICLINIC

	CHARACTERISTICS		
1.	CUBIC — singly refractive (SR)		
2.	TETRAGONAL HEXAGONAL	uniaxial	doubly refractive (DR)
3.	ORTHORHOMBIC MONOCLINIC TRICLINIC	biaxial	



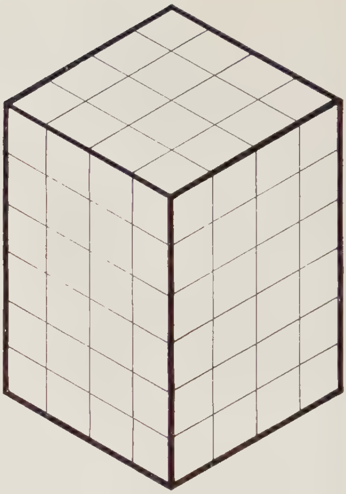
CUBIC (Isometric) SYSTEM. All axes the same length and all at right-angles to each other.

Cubic System

The cubic system has three axes of equal length, all at right angles to each other. In mineralogy this system is called isometric, meaning equal measure, in reference to its three axes of equal length. In drawings, the axes of this system are designated as a_1, a_2, a_3. All minerals crystallizing in this system are singly refractive and include: *diamond, all garnets, spinel, fluorite,* pyrite, lazurite, sphalerite, pollucite, rhodozite, cobaltite, and chromite.

Most minerals have a crystal form in which they are *usually found.* This form is called their crystal *habit.* The habit of fluorite is the cube; diamond and spinel, the octahedron; and the habit of garnet is the rhombic dodecahedron.

These three forms, the cube, the octahedron, and the rhombic dodecahedron. are closely related through the crystal structure of the cubic system. The octahedron is simply a cube with each of its twelve edges progressively cut down until only a point remains at what was the center of each face of the cube. The dodecahedron is formed by cutting down the edges of the octahedron in the same manner to form a twelve-sided figure. These three forms can also be combined to yield a variety of complex forms. There are many other variations that can be developed from the cube. Those interested can find them illustrated in *Dana's Textbook of Mineralogy*, pages 71 to 91.



TETRAGONAL SYSTEM. All axes at right-angles to each other, two of equal length but the third is either longer or shorter than the other two.

Tetragonal System

This system also has *three axes all at right angles to each other,* but they are not of equal length. *Two are of equal length, the third may be either longer or shorter.*

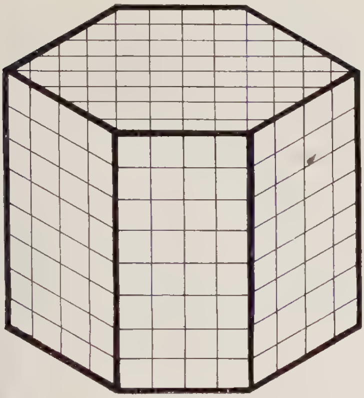
To visualize this crystal form, think of a cube that has been vertically stretched somewhat until its height is greater than its width and thickness. Or, if its vertical axis is shorter than the other two, it will appear vertically flattened. In either case, when viewed at its top or bottom, it would appear a perfect square. In drawings, the two equal axes are designated as a_1, and a_2, the vertical axis as c.

Gem minerals crystallizing in this system are: *zircon, rutile, idocrase,* scapolite, cassiterite, anatase, scheelite, wardite, and apophyllite. They are doubly refractive and uniaxial.

Hexagonal System

This is the only system having *four axes. Three are of equal length meeting in a horizontal plane at angles of 60 and 120 degrees. The fourth, or vertical axis may be either longer or shorter and is at right angles to them.* The three horizontal axes are designated as a_1, a_2, a_3. The vertical axis is c.

Gem minerals in this system are:



EXAGONAL SYSTEM. The only system ith FOUR AXES. Three are of equal length a horizontal plane and meet at angles 60 degrees to each other. The fourth ertical or c axis) is longer or shorter than e other three and meets them at a right ngle. All three horizontal axes lie in this ane so cannot be shown separately.

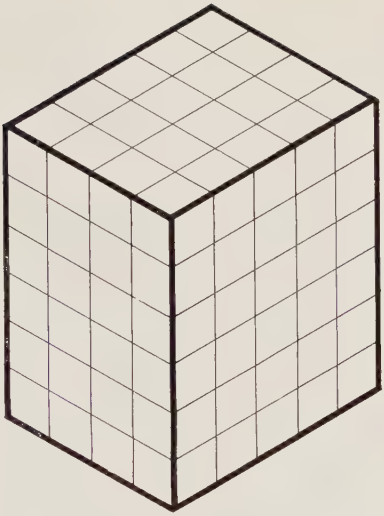
uartz, beryl, corundum, tourmaline, enitoite, apatite, zincite, phenakite, illemite, hematite, dioptase, smithson- e, rhodochrosite, and calcite. They are oubly refractive and uniaxial.

Orthorhombic System

Orthorhombic crystals have *three xes, all at right angles to each other, ut all different lengths.* The shortest is esignated as *a*, the slightly longer axis s *b*, and the vertical axis as *c*.

Gem minerals of this system are: *paz, peridot, chrysoberyl,* iolite, beryl- nite, andalusite, danburite, kornerup- ie, enstatite, prehnite, staurolite, and ragonite. They are doubly refractive, nd biaxial.

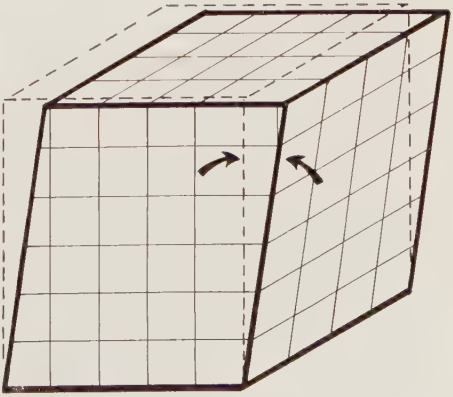
To visualize the axial relationship of is system, think of an ordinary wash- g powder box, such as Vel or Cheer. hink of the axes as extending from the nter of each face to the center of each pposite face, through the center of the ox. Mentally stand the box up, with e large flat side facing you. The short- t axis, *a*, will be through the shortest imension of the box from front to back. xis *b* will extend from left to right; the ertical axis *c*, from top to bottom. If ou can do this satisfactorily, store away is mental box, we will use it again for e monoclinic and triclinic systems.



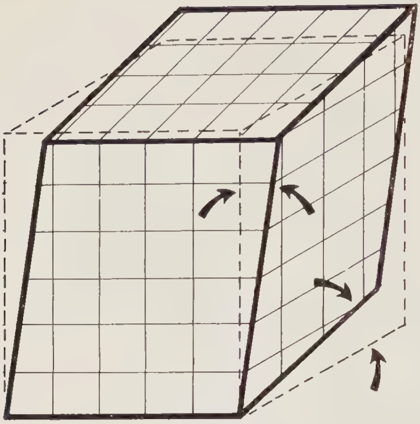
ORTHORHOMBIC SYSTEM. Three axes, all meet at right angles to each other, but all three are of different length.

Monoclinic System

This system also has *three axes. All are different lengths. One is inclined to the other two.* Get out your mental soap powder box and we will easily visualize the axes of this system. Consider the axes as extending from the center of each face on the box to the center of the opposite face. This time, lay the box on one of its narrow sides with the broadest side facing you and the two



MONOCLINIC SYSTEM. All axes are of different lengths. Two meet at right angles to each other but the third is inclined to these two making an angle with the others that is greater or less than 90 degrees. The arrows show the angular displacement of the vertical axis.



TRICLINIC SYSTEM. All axes are of different lengths and all of them meet at an angle that is more or less than 90 degrees. The arrows indicate the angular displacement of the axes.

small ends to right and left. Now mentally touch the top side with your finger and tilt it away from you while still leaving the base flat on the table. This will make the ends rhomboidal in shape. Now tilt the whole box forward until the side facing you is vertical. Note that the axes *a* and *b*, and *b* and *c* are at right angles to each other. But axis *a*, called the clinoaxis, is inclined to *c* and tilts toward you as you face the box.

Save the box!

Gem minerals of the monoclinic system are: *orthoclase feldspar, spodumene,* brazilianite, euclase, sphene, epidote, diopside, datolite, and gypsum. They are doubly refractive, and biaxial.

Triclinic System

The triclinic system has *three axes, all different lengths, all inclined to each other.* Get out the soap powder box! With two previous tries it should be easier this time to visualize the axial relations. Mentally lay the box on its side (the long dimension horizontal) a flat side facing you. Tilt it to the right. Then turn it so the end faces you, and tilt it to the right again. Now you have it. Yes, a double tilt, so that each axis is inclined to the others. Let axis *a* remain the short dimension. Axis *b* is in the long horizontal dimension, and *c* is the vertical axis. All are inclined to each other. You may now throw away your mental soap box.

The above mental calisthenics with the soap box should be easy for a rockhound for he can always see his friend's tomcat-in-an-agate-slab. Some of the cats take a lot of imagination, but any good rockhound can do it. He may even find one in his own agate.

Gem minerals of the triclinic system are: *all feldspars except orthoclase,* axinite, kyanite, rhodonite. They are doubly refractive and biaxial.

Chapter 7

Light, Color, Brilliance and Luster

All of the mysterious beauty of gems lepends upon light. The use of light in ptical identification methods makes it ossible to identify most gems correctly vithout resort to methods which might leface or destroy a stone. The behavior f light rays within gem materials and n gem testing instruments is of the reatest importance in gemology.

Since the action of light is of such mportance in gem identification, we hould know something about the the-ries or physics of light. There seems no ecessity for a long or deep study of the ubject, so we will briefly explain the nore important details that are of inter-st or that are necessary in the study f gemology.

When we see the sun rise in the morn-ng, we observe the sensation known as ght and can see other objects which e could not see in the darkness of ight. We have heard that the brightness f the full moon is nothing more than reflection of the sun's rays from its urface. For the majority of us, this s all we are interested in. For the study f gemology we are going to learn just little more about the action of light ays, to give a better understanding of uch terms as dispersion, dichroism, ouble refraction, birefringence, refrac-ve index and others, which as yet may e only words, but which will become ompletely understandable as these les-ons progress. These words are the hought tools of gemology.

Theories About Light

Science still seems somewhat uncertain bout the subject of the production of ght and its transmission from point to oint. In the past, various theories have een advanced to explain the action of ght as it was then known. Each theory aried somewhat from those before it. o doubt science will learn much more bout it during the current "atomic ge."

In the year 1666, Sir Isaac Newton dvanced the "emission" or "corpuscular" theory of light. According to his theory, a luminous body emitted streams of very tiny particles, *in straight lines* from the light source. These very tiny particles were able to penetrate transparent materials. When these corpuscles entered the eye and stimulated the optic nerve, they produced the sensaiton we know as light.

However, in 1678, the great Dutch physicist, Huygens, advanced the theory that the light rays from a luminous body came from it as a series of wavelike rays with an undulatory motion, traveling through the medium of the *ether*. The wave motion started by successive parts of the ether setting each other in motion. This ether was assumed to be an extremely tenuous medium pervading all matter.

Later, James Clerk Maxwell modified this theory by saying that light is composed of ether waves caused by vibrations due to periodic alterations in the electric and magnetic conditions of the ether. This is termed the "electromagnetic" theory, and is the theory generally accepted at this time when considering the practical applications of light.

Dana, in his book on theory, states that light is due to a periodic variation in the energy given off by vibrating electrons. The more modern quantum theory of Nils Bohr is too complicated for these lessons and would not aid us in picturing in our minds the action of light in gem minerals.

How Light Travels

From a point source, light travels in all directions until it is interrupted by a reflecting or absorbing material in its path. It is difficult to theorize on light traveling in all directions, or light striking a gemstone from all directions, so we will use a theoretical single ray for our theorizing.

Light travels in an undulatory or wave-like manner and if a single ray is travelling in any direction, let us say due east, it will be vibrating in all directions at right angles to that direction, that is, north and south, up and down, and all directions in between. When light travels from one point to another, nothing moves along the route but the light *energy* which is transmitted by creating a series of compression and rarefaction areas along the route. This is not a movement but a transfer of energy along the route travelled. Imagine several billiard balls placed in a row and touching each other. Striking the first ball will move the last ball only, the balls in between passing on the energy but appearing to stand still.

It is important to picture the relation between the direction of propagation or travel, and the direction of vibration. To do this, think of a wheel with a lot of spokes, supported on an axle. If the direction of light propagation is along the axle, the direction of vibration will be in the directions of the spokes of the wheel or at right angles to the direction of the axle. See Fig. 7-1.

Measurement of Light

Light travels in a wave form and the distance from any point on one wave to a similar point on the next wave, is *one wave length.* The intensity of the light energy is determined by the extreme range of the fluctuating wave as it rises above zero. See Fig. 7-2.

White light, as we know it, is composed of all colors of the spectrum. The principal colors are: red, orange, yellow green, blue, violet. When all of these colors strike the optic nerve at the same time we get the sensation of white light. The color of the light depends upon its wave length. The color we know as violet has the shortest wave length and red has the longest wave length. See Fig. 7-3.

To measure these wave lengths by meters, or even by centimeters, would make rather unwieldy figures. A yellow light ray would measure 0.00005896 centimeter. Instead, a unit of measurement was established and named after the Swedish scientist, A. J. Angstrom, in 1886. It is called an angstrom unit (AU or A). An angstrom unit is a linear measurement ten millionths of a millimeter in length. The wave length of yellow light is said to be 5896 AU in length.

Our eyes see only a small portion of the wave lengths we know are in the electromagnetic spectrum. The portion that is visible is between the wave lengths of 4000 and 7000 AU, approximately, or from violet to red. Invisible wave lengths below 4000 are called ultraviolet, and as the wave lengths get shorter we have X-rays, radium rays, and cosmic rays. As waves get longer than the visible red rays of 7000 AU, we have infrared or heat waves, then radio waves.

Transparency

An object that transmits light readily is said to be *transparent,* such as air, glass, water, some gem stones, etc. A gem material is said to be transparent when so many of the light waves are transmitted through it that the outline of an object viewed through it is clear and distinct. If the image viewed is somewhat blurred or indistinct, whether because of absorption of light or cloudiness caused by inclusions, the material is termed *semitransparent.* Synthetic rutile is usually semitransparent. Diamonds are usually transparent.

If a large amount of blurring or distortion is present, yet some light passes, the material is said to be *translucent.* Clear agate or chalcedony is often translucent.

Semitranslucent material is that which we would ordinarily call opaque except that some light passes through a thin section. Lapis lazuli or jasper is semitranslucent.

Opaque indicates a material through

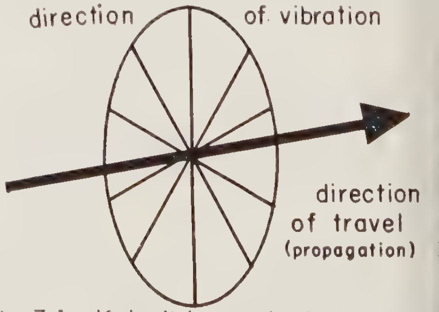
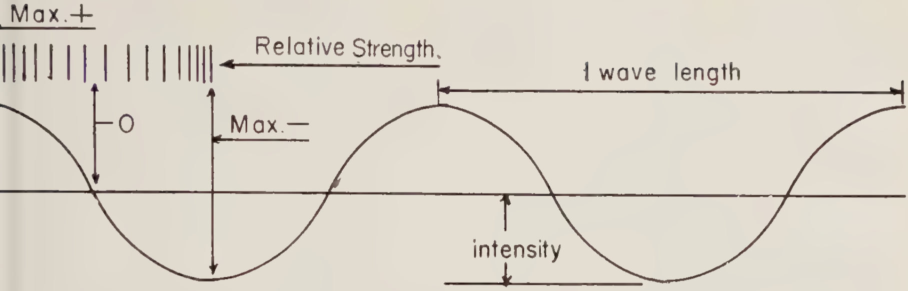


Fig. 7-1—If the light travels along the axis of the wheel it will vibrate in all directions, at right angles to the axis. The wheel spokes show some of the directions of vibration but there are, in reality, an infinite number of "spokes."



g. 7-2—The propagation of light (or any electromagnetic energy) is actually in the form alternate areas or volumes of compressed and rarefied matter. This is usually shown aphically in the form of a wave to indicate the positions of maximum and minimum mpression. However, "waves" of light actually "vibrate" in all directions around the direc- on of travel and should not be thought of as a two-dimensional form but as a three- mensional form.

ich no light whatever will pass, even en cut to a thin section. In gem min- als, the only true opaques are the etallics such as pyrite, marcasite, and matite.

Alteration of Light

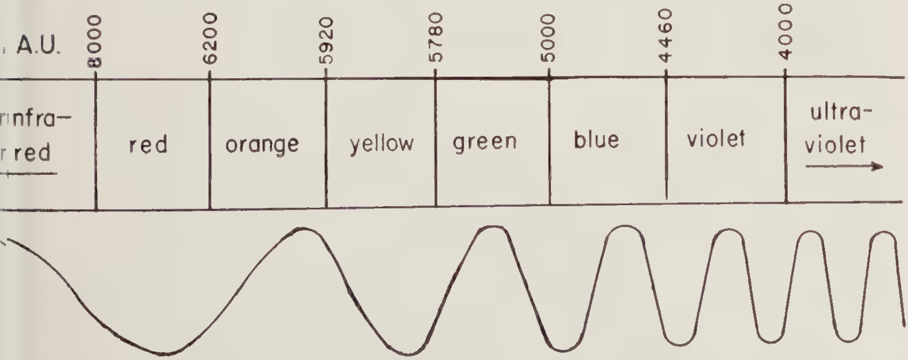
The degree of transparency of a ma- rial depends upon the *amount* and *na- re* of the light that passes through it. ne amount of light transmitted depends gely upon the structure of the ma- rial. Light rays may pass through a aterial with no appreciable distortion t because of its peculiar structure hich causes it to absorb much of the ht rays, it cannot be classed as com- tely transparent. Dark red garnet is this type.

The nature of the light transmitted pends upon the obstacles it meets thin the material, such as inclusions laminated structure. Examples are oonstone or cat's-eye minerals.

The structure of colored materials may be such that part or all of certain wave lengths of light are absorbed as light is transmitted through them. The wave lengths that are passed are the ones that give the apparent color to the material.

For instance, ruby passes nearly all wave lengths to some degree but passes red and blue most easily, so the mineral appears red with a slightly purplish tinge. Alexandrite passes green and red about equally, *so whichever color predominates in the light by which the stone is observed* gives color to the stone. Alexandrite appears green in daylight and red by incandescent light. This property of absorbing part and passing part of the light is called *selective absorption of light.*

If a stone passes all wave lengths equally, it is *colorless.* If a stone absorbs all wave lengths equally, it will appear



. 7-3—Light is only a very small portion of the electromagnetic spectrum which includes rything from the very long heat waves to ultra-short X-rays and cosmic rays.

black. If a stone reflects all wave lengths equally, it will be *opaque* and *colorless.* If it reflects only certain wave lengths and absorbs others, it will be opaque and colored according to the wave lengths reflected.

To those who are looking forward to the more practical parts of these lessons, the how-to-do-it parts, some of these explanations and theories may seem dry and uninteresting.

Two Color Types

The absorption of certain wave lengths of light is often due to the presence of metallic oxides which have no essential part in the mineral's composition, but are accidentally present in such small quantities that their presence can be proven only by the spectroscope.

Of these light absorbing oxides, the more common are: iron, which causes yellow and yellow-green, and is believed by some to be the cause of the violet color in amethyst; chromium, which causes the red in ruby and the green in emerald; titanium, giving a blue tint; lithium, giving a pink tint; and manganese, a violet color. Other less common coloring materials are nickel, vanadium and cobalt.

Minerals colored as above, where the coloring oxides are not an essential part of the mineral, are termed *allochromatic.* If the coloring oxides were left out, the minerals would be colorless. Quartz, beryl, spinel, corundum, in fact, most gem minerals are allochromatic.

If the coloring matter is an essential part of the mineral's composition, such as the copper in turquoise, malachite, and azurite, the mineral is termed *idiochromatic.* If the material causing the color were left out, it would be a different mineral. Peridot is the only common transparent idiochromatic gem mineral.

Be sure to remember these terms: allochromatic and idiochromatic. Allochromatic minerals are those in which the color is accidental to the composition. Idiochromatic minerals are those in which the color is an inherent part of the composition.

If a strongly colored allochromatic mineral is broken up and pulverized, the powder will appear white. If tested on a streak plate, the streak will be white Idiochromatic minerals, if powdered will retain their color and will show a colored streak on the streak plate.

Dispersion

Dispersion is the property or ability of a gem mineral to separate white ligh

GEMOLOGICAL TABLE OF DISPERSION

(Important stones are in boldface type)

Mineral	Approx. RI	Disp.
APATITE	1.65	.013
ALMANDITE	1.77	.024
BENITOITE	1.75	.046
BERYL	1.57	.014
CASSITERITE	2.00	.071
CHRYSOBERYL	1.75	.015
CORUNDUM	1.76	.018
CROWN GLASS	(variable)	.016
DANBURITE	1.63	.017
DATOLITE	1.62	.016
DEMANTOID	1.88	.057
DIAMOND	2.41	.044
DIOPTASE	1.65	.022
EPIDOTE	1.73	.030
EUCLASE	1.65	.016
FLINT GLASS	(variable)	up to .041
FIBROLITE	1.65	.015
FLUORITE	1.43	.007
HESSONITE	1.74	.028
IDOCRASE	1.71	.019

Mineral	Approx. RI	Disp.
IOLITE	1.53	.017
ORTHOCLASE	1.53	.012
PERIDOT	1.65	.020
PHENAKITE	1.65	.015
POLLUCITE	1.51	.014
PYROPE	1.74	.023
QUARTZ	1.54	.013
RUTILE	2.62	.285 to .305
SCAPOLITE	1.54	.017
SINHALITE	1.65	.017
SPESSARTITE	1.79	.027
SPHALERITE	2.36	.156
SPHENE	1.90	.051
SPINEL	1.72	.020
SPODUMENE	1.66	.017
STRONTIUM TITANATE	2.41	.198
TOPAZ	1.62	.014
TOURMALINE	1.64	.017
ZIRCON	1.92	.038

to its component spectral colors. A
ore common name for dispersion is
ire." White light is not a color but a
ixture of all the colors the eye is able
see. All visible light wave lengths
iking the optic nerve, with equal in-
nsity, give the impression of perfect
ite light.

For the present we are concerned
ith dispersion as a color effect in gems.
the next chapter, after we have ex-
ained the properties of reflection and
fraction, we will give more details,
th drawings and explanations, of how
ght is divided, or dispersed, as it passes
rough a gem to give the effect we call
spersion.

Dispersion is the property that gives
ms the ability to separate white light
to spectral colors. This effect varies
dely among the different gem min-
als. Diamond, considered a "fiery"
m, has a dispersion of .044. Fluorite
lowest with .007. Others are: zircon,
38; sphalerite, .156; and synthetic
tile about .300. These figures and
ose in the accompanying table, repre-
t the difference in the dispersive
wer of the minerals. They are the
sult of a subtraction of the figures of
refractive index for the red ray
867 angstroms) from those of the re-
active index of the violet ray (4308
). This will be explained fully in the
xt chapter.

The colors seen as the result of disper-
on are not solid, constant colors, as the
l of garnet or the blue of sapphire, but
e the colors that vary with the tilt of
e stone and the angle of the eye. Dis-
rsion is not a part of, nor is it consid-
ed a factor in, the brilliance of a gem-
one. To show dispersion to a maxi-
um degree, a stone must be correctly
t. Of course, those low in dispersion
ch as fluorite, no matter how well cut,
n never display an appreciable amount
dispersion. Conversely, synthetic
tile, even if rather poorly cut, will
pear highly dispersive.

Diamond (.044) requires careful cut-
g to display the "fire" of which it is
pable. Many diamonds are cut for
ximum carat weight rather than max-
um "fire" and brilliancy and are
en quite unimpressive. In general,
dispersion increases as the refractive index increases. With very few exceptions, the higher the refractive index, the higher the dispersion.

Brilliancy

Of the light striking the top facets of a stone, the amount returned to the eye is the gauge of its brilliancy. The four factors affecting brilliancy are first, and most important, refractive index. The higher the refrective index the greater the stone's brilliancy. Regardless of other factors, a stone of low refractive index can never be a brilliant stone.

Second, correctness of cutting. (In the jewelry trade, the cut of a stone is called its "make.") A correctly cut stone has its facets cut at the proper angles to bring out maximum brilliancy, in other words, to return a maximum amount of light to the eye.

Third, the transparency of the stone, or how much light may be transmitted through it. Diamond is often completely transparent and is considered the most brilliant of gems. Synthetic rutile, a very brilliant stone, is never completely transparent, so cannot equal a well cut diamond in brilliancy. Synthetic rutile has a higher refractive index and higher dispersion but due to its lack of complete transparency cannot display top brilliance.

The fourth factor is polish. If the light is to be refracted into the stone, or reflected from its surface, the stone must be well polished. A soft stone cannot be polished to as high a degree as a hard one. This is another reason why synthetic rutile cannot be made to equal diamond in brilliancy. Rutile is 6½ in hardness, while diamond is 10, a very great difference.

Be sure to remember the four factors affecting brilliancy: refractive index, cut, transparency, and polish.

Luster

The appearance of a surface by reflected light is called its *luster*. The degree or intensity of the luster depends largely upon the refractive index and the polish of the surface. The luster of of a surface may be modified by light reflections from within the stone, as in tigereye. When so modified, the effect is called *sheen*.

In some circles the term sheen is applied to the moonstone effect. It is seldom so used in this country. The lustrous effect noted on the surface of a pearl is neither luster nor sheen, but is called *orient.*

The different degrees of luster noted on gem minerals are as follows:

Metallic—the appearance of most metals and a few gem minerals. The most common is pyrite, or "marcasite" as it is called in the jewelry trade.

Adamantine—this diamondlike luster is the most brilliant, other than metallic. To show adamantine luster a material must be of high refractive index and be hard enough to take a good polish. Gems of adamantine luster are: diamond, zircon, and corundum. Zircon and corundum must be well polished. Adamantine luster will be seen on a fractured surface of all gem minerals of high refractive index.

Subadamantine — a luster somewhat less brilliant than adamantine. Most garnets when well polished display a subadamantine luster.

Vitreous or glassy — this is the luster of glassy substances and most gem minerals of low or medium refractive index, such as quartz, beryl, topaz, etc.

Resinous or greasy—noted on surfaces with a slightly mat appearance. Amber has a resinous luster on fracture surfaces.

Waxy—less bright than resinous. May be seen on fracture surfaces of some chalcedony.

Dull—an absence of luster. A rather coarse mat surface. May be seen on rough turquoise and fracture surfaces of most chalcedony.

Silky—noted on minerals with a fibrous body appearance, such as on tiger-eye and satin spar. This is one type of the surface appearance called sheen.

Pearly—this type of luster is seen on most pearls and on rough moonstone. It is the result of an internal structure of many thin laminations or a surface consisting of many very fine overlapping scales.

The luster of a material is sometimes quite useful in gem identification. To properly observe the luster of a stone, hold the specimen toward a good light and note the surface by *reflected* light. The light source should not be too intense.

It is sometimes difficult to note the difference between a vitreous and resinous luster, or between a subadamantine and a vitreous luster, but an adamantine luster on cut or rough material is easy to define. On fracture surfaces, the appearance of a luster is of great value for identification. Rough sapphire is easily distinguished from quartz, beryl, etc. One of the most common uses of luster is the identification of chalcedony through the dull or waxy luster on a fracture.

When opportunity offers, observe the great difference in luster between rough zircon or sapphire and quartz or beryl.

In trying to explain the various terms used in gemology, it is sometimes difficult to avoid using other, perhaps bigger, words that may not have been fully explained. Reading through these lessons once or even twice, is rarely sufficient. After reading through a new lesson, read through one or two of the the older lessons and each time you reread the older lessons a different and better understanding will be reached because of increased knowledge resulting from the lessons in between.

hapter 8

eflection, Refraction and Brilliance

In this chapter we approach the most iteresting of the optical properties of em minerals, reflection and refraction f light. Most persons will think they now all about reflection. They may y, “It is simple; I have seen light eflected from auto windshields, from ne surface of a lake, and from a mir- or.” They may even remember using a nall mirror for signalling when a oungster. But that is only the begin- ing.

The two simple laws of reflection are: . *The angle of incidence and the angle reflection are equal. 2. The incident y, the normal, and the reflected ray, e all in the same plane.* Be sure you nderstand and remember them.

In explaining this and other optical roperties, usually we will show a cross- ction diagram of a brilliant-cut gem- one, and show the action of a single y of light as it is reflected, refracted, c. A single ray of light is, of course, npossible to achieve, but it is a very seful tool for theorizing and diagram- g, even if imaginary. One must re- ember that in actuality, millions of light rays will be striking the stone’s surface from every possible angle, but each will follow the same laws and will be reflected or refracted according to those laws.

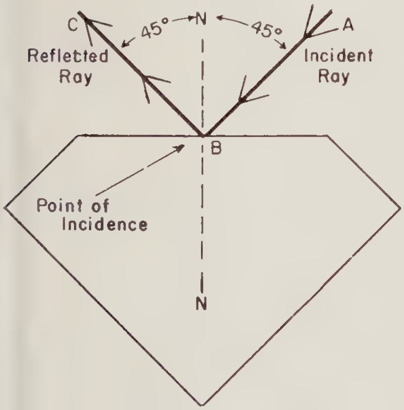


Fig. 8-1
A — Incident Ray.
B — Point of Incidence.
C — Reflected Ray.
N — Normal.

The word “normal” is a geometrical term meaning perpendicular to a given line or surface. As used in gemology it is an imaginary line perpendicular (at right angles) to the surface of an object such as the facet of a stone. If we say “23 degrees from the normal,” we mean an angle of 23 degrees from an imaginary line perpendicular to the surface. Every ray of light that strikes a surface will have a normal at its point of incidence (the point at which it strikes the surface).

The important point to remember about reflection is that the angle at which the ray strikes the surface of the stone is the angle at which it leaves that surface. If it strikes the surface at 30 degrees it will be reflected at 30 degrees. If it strikes the surface at 15 degrees it will leave that surface at 15 degrees.

However, not all the light that strikes the surface of a stone is reflected away. Part of the light will be *refracted* into the stone. The amount of light reflected from a surface depends upon the refractive index of the material, the degree of polish of the surface, and the angle at which it strikes.

Light striking the surface at an angle of 90 degrees from that surface (the direction of the normal) is not reflected but is, for practical purposes, entirely refracted into the stone.

Reflection of light plays an important part in the brilliance of cut gems, as well as in their luster or sheen. The play of color in opal, asterism or the star in asteriated stones, chatoyancy in cat’s-eye stones, and other optical phenomena in gems, are largely the result of the reflections of light from their surfaces and inner structure.

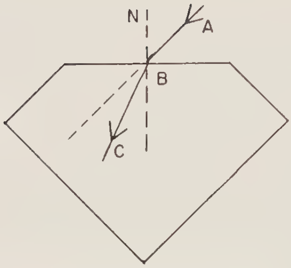


Fig. 8-2

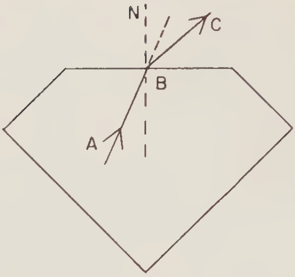


Fig. 8-3

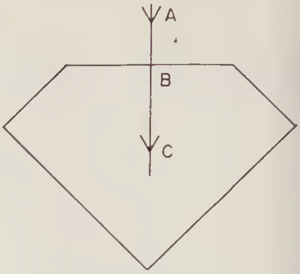


Fig. 8-4

A—Incident ray. B—Point of Incidence. C—Refracted ray. N—Normal.

$$\frac{186{,}000 \text{ (Speed of light in air)}}{\text{Speed of light in denser material}} = \text{RI of denser material.}$$

or—

$$\frac{186{,}000}{\text{RI}} = \text{Speed of light in denser material.}$$

Everyone at one time or another, has observed how a stick appears to be bent where it enters water. Remember how an oar looks when you push it into the water to fend off a small boat? Or have you ever tried to shoot or spear fish? If so, you soon found it was necessary to aim well below the apparent position of the fish. This bending of the light rays as they enter a different medium is called *refraction.* However, light that enters perpendicularly to the surface is not bent, but passes straight through from one medium to the other.

Note that in Fig. 8-2 where the ray is entering the stone, the ray is bent from its straight path *towards the normal.* In Fig. 8-3 where the ray is leaving the stone, it is bent *away from the normal.* These are points you should remember. In Fig. 8-4 where the incident ray enters perpendicularly to the surface of the stone, it is not bent but passes straight through.

We must consider any gem material as a medium denser than air, optically denser, and light slows down as it enters a denser medium. Light travels in air at approximately 186,000 miles per second. In diamond it travels approximately 77,000 mps. The relation between these speeds is the refractive index (often abbreviated R.I., or RI) of the material. The R.I. of a material is the *ratio of the speed of light in that material to the speed of light in air.* The more optically dense a mineral is, the more it will slow down light, and the higher will be the R.I. The equations are given above.

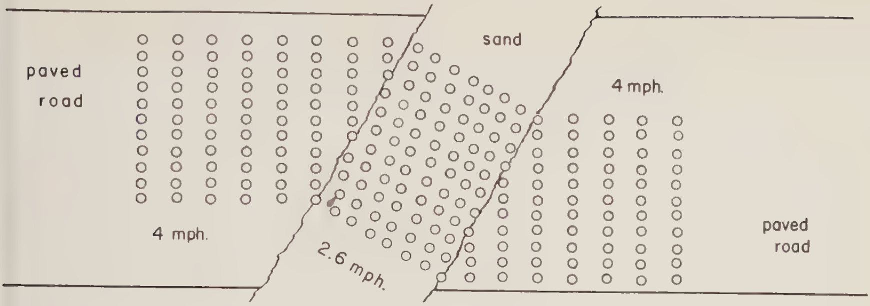
The reason light is bent when it slows down is probably best explained by the well known analogy of the marching soldiers. Consider a body of soldiers marching ten abreast on a well paved road, at a speed of four miles per hour (mph). Arriving at a diagonal washout in the road, they have to march across deep sand to reach the pavement on the other side.

The first soldiers to reach the diagonal break will be slowed to 2.6 mph when they hit the sand, while the others in the same row will still be walking 4 mph, thus causing a bending of the line of march. The same thing will occur but in the reverse, as they reach the next pavement and regain their marching speed of 4 mph. Shall we see how this would work out mathematically?

Would this 1.54 be the RI of the sand? If so, the sand must be all quartz! Oh, well.

But a ray of light acts like the column of soldiers in the sand, it is bent as it slows down, and bent in the opposite direciton when it picks up speed again.

The method of calculating the degree of bending of the refracted ray is simple. It is seldom necessary that a gemologist do this, but we feel that he should be able to do so. It is very interesting and instructive to plot the path of several rays of light through a gem stone, by



$$\frac{\text{Speed of light in air (soldier's marching speed)}}{\text{Speed of light in denser material (speed in sand)}} = \text{RI}$$

$$\frac{\text{4 mph}}{\text{2.6 mph}} = \text{RI} = 1.54$$

awing its outline, setting its facet an- es with a protractor and calculating e various angles of refraction or re- ction as the imaginary ray passes rough the stone. This should be of rticular interest to those facet cutters o wish to calculate or verify their n cutting angles to get the maximum illiance and dispersion from the stones ey cut. After studying this and the xt few chapters they should be able do this easily.

The only arithmetic required is divi- on and multiplication with just a ch of trigonometry. The amount of g is only that you be able to read rtain figures from a column in a trig- ometry table. Just skip the next veral paragraphs if you are not in- ested.

Snell's Law of Refraction

1. When a ray of light passes from e medium into another, the *sine of* *angle of incidence* bears to the *sine* *the angle of refraction* a definite io which depends upon the two media contact and the nature (wave length) the light.

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

Do not bother to memorize these.

The ratio between the sine of the gle of incidence and the sine of the gle of refraction is the refractive in- x. Therefore, the equation for actual is:

$$\frac{\text{ne angle of incidence}}{\text{efractive Index}} = \text{Sine angle of refraction}$$

Which is usually abbreviated to:

$$\frac{\text{Sin } i}{\text{RI}} = \text{Sin } r$$

To those who have even an elementary knowledge of trigonometry, the equation is simple. To those who have no knowledge of trigonometry, the only strange word is "sine." We will not try to teach you trigonometry. It is unnecessary. Let the word sine mean only a certain column in a book of trigonometric tables. Such books are available in all book shops. The simplest and cheapest, about 50 cents, is best for our purpose. Just be sure it includes a column of natural sines. Such a book can be borrowed from the public library.

As an example, let us work a problem together. Consider a brilliant-cut quartz gem stone with a ray of light striking the table at an angle of 35 degrees. What will be the angle of refraction? First, we must substitute numbers for the words in the equation. The first part, "sine angle of incidence," or "sine i." The angle of incidence is 35 degrees, so we must look in the trig table book on the page allotted to the angle 35 degrees. Note that the pages go from 0 to 44 degrees, with the degrees marked at the top of the page. The various column heads are marked: M (minutes), Sine, Cosine, Tan (tangent), Cotan (cotangent), Secant, Cosec (cosecant), all columns reading down. If the angle is over 44 degrees, look for the degree number at the bottom of the page, and the columns all read up.

On the page marked 35 degrees (35°),

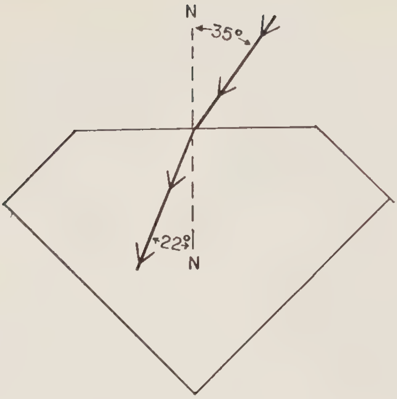


Fig. 8-6

in the sine column, on the 0 minutes line, the number .5736 appears. In our equation this is the number to put in place of "sin i." Write it in. Next is the RI, which for quartz is 1.54. Write that below the division line. Now carry out the division indicated by dividing .5736 by 1.54. This should equal .3724, which according to our equation is the sine of the angle of refraction.

Now to find just what angle .3724 is the sine of, look down the sine columns of the various degrees until you come to .3724 (this will be on the page marked 21°) where you will find .3724 on the 52 minutes line. So our angle of refraction is 21° 52′ (21 degrees, 52 minutes). There are 60 minutes in each degree, so 22 degrees will be a very close answer.

Note that in Fig. 8-6 the angle of incidence is 35° *from the normal*, and that the angle of refraction is 22° *from the normal*.

We suggest you try several similar problems. Use a protractor and plot them on paper to see just how the angles look. Try a problem using the same angle of incidence on a stone of spinel (RI 1.71). The angle of refraction will be about 19° 35′. Note that the higher the RI, the greater the bending of the refracted ray. Try another problem using diamond (RI 2.41). The angle of refraction will be a little under 14°. All such problems can be quickly worked with an ordinary slide rule if you can use one or if you are willing to learn and practice a little.

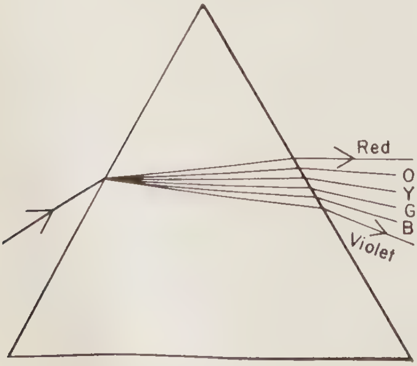


Fig. 8-7

You will not have such problems in actual gem identification, but understanding them will give you a much better idea of the action of light in gem stones and increased knowledge always increases self-confidence. Save your trig table book, you will find further interesting uses for it when we reach the discussion of critical angle and tota reflection of light.

More About Dispersion

You have learned about refraction how the light is bent as it enters medium of greater optical density. I should now be easy for us to explain more about color dispersion.

In Chapter 7 we told you a little about dispersion in so far as it affects the apparent color of gems. Now we wil tell you just how white light is separate to show these dispersive colors. When light is refracted into a denser material it is bent. The shorter wave lengths o light (violet) are bent more than th long wave lengths (red), so some degre of separation results each time the ligh is refracted whether entering *or* leavin the stone.

The degree of separation is small i minerals of low dispersive power, suc as fluorite, orthoclase, and quartz, bu increasingly larger as the dispersiv power increases. In general, the dispersive power follows the R.I. The highe the R.I. the higher the dispersion, bu there are several notable exceptions suc as benitoite, demantoid, and sphene. A are higher in dispersion than diamon but all are lower in R.I. Check the tabl of dispersion.

Figure 8-7 shows the dividing of a ra of white light as it enters a prism, an how it is further spread as it is r acted out through the second surface. 1 a brilliant-cut stone, some rays of ght that strike the top facets will be efracted through that surface. Some ispersion will occur and the divided ght will strike the inner surface of a ack facet where it will be reflected cross to a facet on the opposite side nd again reflected to a top facet, where is refracted again on leaving the stone. t each surface where it is refracted, the egree of dispersion will be increased id if the dispersive power of the min- al is sufficient, there will be a notice- ble amount of dispersion visible from e top facets.

Here is another important point. The mount of visible dispersed light de- ends very much upon the *angle at hich the ray leaves the stone.* If it is fracted out at an angle of 90 degrees, perpendicular to the surface, there ill be *zero dispersion!* If the ray leaves aralled to the surface or as near par- lel as possible and still be visible, there ill be the *maximum amount of disper- on* of which the mineral is capable. This is why proper cutting angles are important in bringing out the disper- on or "fire" in gem stones. It will also plain why we never see any dispersion rough the table of a stone when look- g directly down into a stone. The one must be tilted to see the dispersion rough the table. Star facets and girdle cets are important for the display of spersion. In both Figs. 8-7 and 8-8 owing dispersion, the amount of light read has been greatly exaggerated. For any stone to display maximum spersion, it must be fully transparent and not too dark in color. Gem quality diamond (disp. .044) is usually quite transparent and nearly colorless. When properly cut diamond is noted for dispersion.

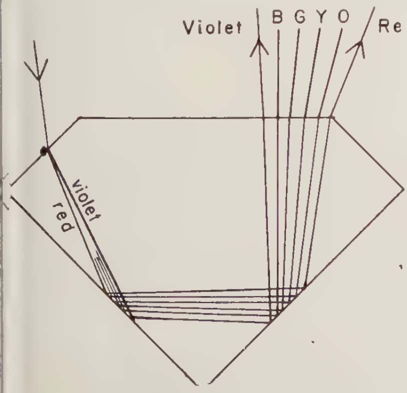


Fig. 8-8

Other gems of higher dispersion such as sphene (.051), demantoid (.057), cassiterite (.071), and sphalerite (.156), are seldom completely transparent and are usually colored to an extent that they may almost completely mask the dispersion. Synthetic rutile (.285 to .305 according to direction) is so high in dispersion that its slight color and lack of full transparency are overcome. High dispersion is the most notable factor in visual identification of synthetic rutile.

The color of demantoid, emerald, and peridot may be very similar, but the high dispersion of demantoid will separate it from the others at first glance. The same difference exists between sphene and similarly colored citrine or topaz. The very low dispersion of colorless sapphire easily distinguishes it from diamond or zircon.

Brilliance In Gems

We now come to the most interesting and important of the optical properties of gem minerals. They are important because the brilliancy of any stone depends upon these properties. Those who are really interested will find them very easy to understand. Read this section over at least twice, study the drawings, and follow each marked ray along its path. Try to understand why it is reflected or refracted in each case.

At first glance it may seem somewhat like the famous 30th stanza of Omar Khayyam's Rubaiyat—"What, without asking, hither hurried *whence!* And without asking, *whither* hurried hence!" But it's really not the purposeless. We will try hard to make it understandable.

Critical Angle

What is critical angle? First, we will define it in a few words, then we will explain it with a lot of words, and even draw you a few pictures. *The angle of the last ray of light to be refracted from the stone, measured from the normal, is called the critical angle. At any greater angle with the normal, the ray would be totally reflected within the stone.*

Another definition is: *The angle of a*

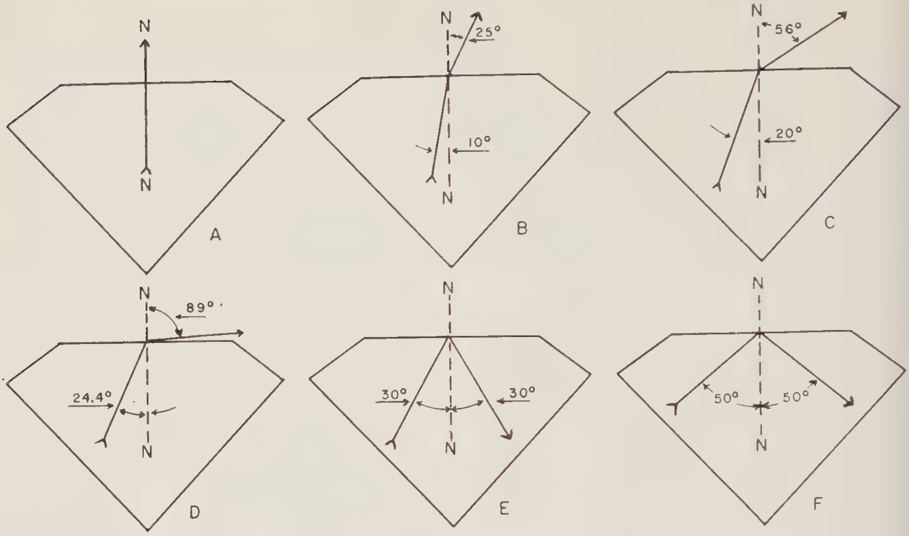


Fig. 8-9

ray of light, measured from the normal inside the stone, which has entered the stone at an angle parallel to its surface.

Notice the similar points in these definitions. The critical angle is formed *inside* the stone, never outside. It is measured from the normal. It is the angle of the last ray to leave the stone before total reflection takes place, or, it is the angle of the ray that has entered parallel, or as near as may be parallel, to the surface.

Let us see just how this affects the brilliancy of gems. In Chapter 7 we explained that brilliancy was the result of light striking the top facets, passing through the stone and being returned to the eye. Then the percentage of the light striking the top facets which is returned to the eye is the measure of its brilliancy.

According to the laws of optics, when light strikes the surface of a stone, some of the light is directly reflected and some is refracted into the stone. When it enters the stone it is bent, and bent toward the normal.

After entering the stone it travels along a straight path until it strikes another surface of the stone. What it does after striking the inner surface of the stone depends upon the following law: *If the ray strikes the inner surface at an angle less than that of the critical angle, it will be refracted through the surface and out of the stone. If it strikes at an angle greater than the critical angle, it will be totally reflected within the stone.*

If it strikes at less than the critical angle it will follow the laws of refraction by leaving the stone and being bent away from the normal. If it strikes at an angle greater than the critical angle, it will not leave the stone, but will follow the law of reflection which says that the angle of reflection is equal to the angle of incidence.

The reason why it is refracted or reflected will be apparent if you examine the drawing in Fig. 8-9 and note the action of the rays as they strike the inner surface of the stone. These drawings are not to an exact scale as they illustrate a principle only. They are based on the approximate angles of light in diamond, R.I. 2.417. The outline represents an enlarged cross-section of a brilliant-cut diamond.

In Drawing A, the ray of light striking the inner surface at 90 degrees from that surface (or at the angle of the normal) passes straight through, no bending.

In Drawing B, the ray strikes the surface at 10 degrees from the normal and is refracted on leaving and according to Snell's laws, will be bent away from the normal at an angle of approximately 25 degrees.

In Drawing C, the angle of incidence s 20 degrees, which gives an angle of efraction of 56 degrees.

In Drawing D, the angle of incidence s 24.4 degrees, which gives an angle of efraction of 89 degrees or just short f 90 degrees which would be exactly arallel to the surface.

So what happens next? In Drawing , the angle of incidence is 30 degrees. he ray has no place to go outside the one. It can no longer follow the laws f refraction, so it does not leave the one but is totally reflected inside and ollows the law of reflection which says e angle of reflection is equal to the ngle of incidence. The angle of incience is 30 degrees, therefore the angle f reflection is 30 degress. This is also nown in Drawing F, the angle of incience is 50 degrees, the angle of reflecon is the same, 50 degrees.

The angle where the change is made om refraction to reflection, where the y ceases to follow the laws of refracon and becomes a reflected ray, is lled the *critical angle*.

One thing should be understood about fraction. The ray will travel the same ath whether it is coming in or going ut. For instance, take Drawing C. If e ray were entering the stone instead leaving at an angle of 56 degrees, its gle of refraction would be 20 derees. The path of light, whether comg or going, will be the same.

A drawing which is almost a classic, ustrating the different events of reaction, total reflection, and critical gle, is shown in Fig. 8-10.

The drawing is used in some books and often by lecturers on the subject. It is most easily understood if drawn with colored pencils or colored chalk, perhaps using red as the ray which just leaves the stone, forming the critical angle, blue for the ray striking inside and green for the ray striking outside the critical angle and being totally reflected. Draw it yourself. It may help you to reach a clearer understanding.

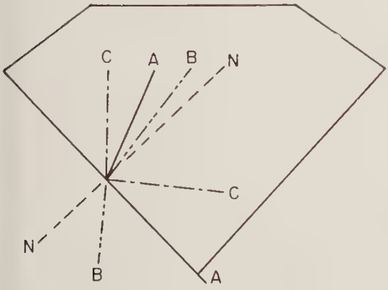
Leakage of Light

If a stone is cut to ideal angles to return a maximum amount of light to the eye, just what must happen to the light that strikes the top facets to get it back to the eye? The light that is refracted into the stone will strike the inner surface of one of the back facets, and at this point it is most desirable that all possible light be totally reflected. Of course, any light that strikes within the critical angle will be refracted out of the stone and lost. This loss is referred to as *leakage of light*. See Fig. 8-11.

Heavy leakage of light can be avoided in two ways: using a material of high R.I. so that the critical angle is small, and cutting the back facets at such angles that a maximum amount of light will strike the surface outside of the critical angle and be totally reflected. The higher the R.I. the smaller the critical angle, and the smaller the critical angle, the less light will leak out.

The light totally reflected at a back facet will strike on the opposite facet on the pavilion of the stone, and again may strike at less than the critical angle and leak out. See Fig. 8-11. If it strikes outside the critical angle it will be reflected to a top facet of the stone.

At the inner surface of the top facets,



g. 8-10. N-N, normal. A to N is critical gle. A-A last ray to leave stone. B-B, y inside critical angle, light leaks out. C-C, y outside critical angle, light reflected.

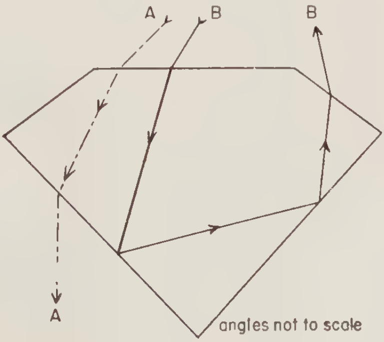


Fig. 8-11.

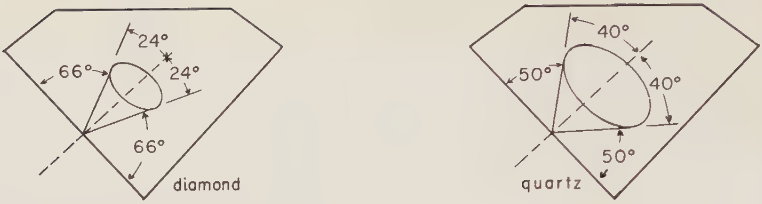


Fig. 8-12

two things are to be desired: first, maximum refraction of light through the surface for maximum brilliancy; second, a maximum amount of light to leave the top facets at angles that are as nearly as possible parallel to the surface, to give maximum dispersion. So, in the calculation of cutting angles, the angles of the back facets have most to do with brilliancy and the angles of the top facets have most to do with dispersion.

There is no easy formula for finding optimum cutting angles. The accepted method seems to be that of making a long series of calculations of the paths followed by light rays striking the top facets at various angles and plotting them on drawn outlines of stones with various angles of back and top facets. It sounds like doing it the hard way but it seems the only way except the often used method of trial and error.

The story is told of Marcel Tolkowsky who spent several years making such calculations for the most advantageous angles for diamond cutting. He finally wrote a book, "Diamond Design," in 1919, giving all his findings. It was found that his recommendations for facet angles were almost exactly that of the then current angles in use by American diamond cutters!

For those interested, Tolkowsky's angles, which are now called the standard American cut, are: crown mains, 34.5 degrees; crown girdle facets 42 degrees; star facets 15 degrees; pavilion main facets 40.75 degrees; pavilion girdle facets 42.75 degrees. So, in this case, trial and error angles proved the same as scientifically calculated angles.

Often we hear the remark by amateur facet cutters, when showing some recently cut quartz or other low R.I. stone, "Look how brilliant. But I couldn't go wrong, I knew the critical angle." But, when asked how they used the critical angle in cutting, they are always vague. There seems to be no real answer to this. Of course, critical angle is necessary if a person is seriously calculating cutting angles. But as a mere aid in cutting — no.

Just why does a small critical angle cause a stone to be more brilliant than one with a large critical angle? Note Fig. 8-12.

The cones drawn around the normal represent the 3D aspects of the critical angle, usually drawn in two dimensions. Light from any direction striking within the cones will leak out. You will see the much larger critical angle cone of the quartz, with its 50 degrees outside the cone as an area of total reflection.

In the diamond, this area of total reflection is 66 degrees. Much less light will fall within the 24 degree cone to leak out. The 66 degree total reflection area allows much more light to be reflected within the stone with a chance of its being returned to the eye. The larger the critical angle, the less the brilliancy.

If you wish to make the calculations of angles of refraction and critical angle yourself, the method was discussed above. Here is additional informaiton.

The equation used for finding the angle of refraction when the light ray is leaving the stone, as in the first drawings in Fig. 8-9, is:

Sin i X R.I. = Sin r
i = Angle of incidence
r = Angle of refraction

In words: The sine of the angle of incidence, times the R.I. of the stone, equals the sine of the angle of refraction. Reread the section above which gave information about finding angles from sines in your book of trigonometry tables.

If the R.I. of a material is known, it

easy to find the critical angle of any aterial.

$$\frac{1}{\text{R.I.}} = \text{Sin Critical Angle}$$

In words: One divided by the re- active index equals the sine of the ritical angle. This is the normal method f finding the critical angle. A short- ut method will be given in a later aragraph.

In the above equation, the unit 1 hich is divided by the R.I., represents e critical angle of air. And the critical gle which results from this equation formed in the stone when it is in ntact with air. The critical angle is rmed in the denser material (the one) only.

The same equation will be effective if other stone is substituted for the air. or the 1 we substitute the R.I. of the aterial of lower R.I. The result will the critical angle formed in the ma- rial of greater optical density when the o are in optical contact.

The equation will read:

$$\frac{\text{R.I.l}}{\text{R.I.h}} = \text{Sin Critical Angle}$$

R.I.l = Material of lower R.I.
R.I.h = Material of higher R.I.

This equation will be referred to hen we explain the theory of the re- actometer.

Here is a short-cut method of finding e critical angle of a single mineral, quiring no calculations and no slide le, but only a simple book of trig bles. Look up the R.I. of the material question, and find the R.I. number in e column marked *cosecant*, often ab- eviated *cosec*. When the number is und, the critical angle of the material ill be the angle at the top of the page us the minutes noted on the line with e cosecant. If you have your tables andy, try it. Take a well known critical angle, such as that of diamond. The R.I. of diamond is 2.417. Find 2.417 in the cosecant column which will be on the 24 degree page. On the same line with the 2.417 is the number of minutes, 26. So the critical angle of diamond is 24 degrees 26 minutes. Could it be simpler? You won't believe it until you try it.

The equation mentioned for finding the critical angle of two materials in optical contact will make it very easy to understand why a diamond is so brilliant when clean and so dull and lifeless when the back facets are covered with grease or greasy dirt, such as accumulates when a diamond ring has been worn rather long without cleaning. Let us find the critical angle of this combination of diamond and grease. The R.I. of diamond is 2.417. The R.I. of the grease and dirt is approximately 1.50.

$$\frac{1.50}{2.417} = .620 \text{ Sin of C.A.}$$
$$= 38.3 \text{ degrees}$$

38.3 degrees then, is the critical angle of the diamond when coated with grease, and is approximately that of glass which has an R.I. of 1.60. So when dirty, a diamond has a brilliance equal only to that of ordinary glass. Moral—clean your stones often—or buy glass, it's cheaper.

To summarize the important facts of this chapter:

Upon entering an optically denser medium, light is bent toward the normal.

When entering a less dense medium, it is bent away from the normal.

The critical angle is formed only in the stone, or in the stone of higher R.I. if two stones are in optical contact.

Light striking inside the critical angle is refracted out of the stone.

Light striking outside the critical angle is totally reflected inside the stone.

Chapter 9

Single and Double Refraction

This chapter will explain more of the important optical properties of gem minerals. Read it carefully. Many practical, experienced gemologists do not understand just what causes double refraction. They may understand its practical aspects, how to use it in identification, but not the basic "why."

To understand this best, think back to the chapter on crystals. We said that the only one of the six crystal systems having perfect symmetry is the cubic system. A cube has six faces, and these faces are identical. Every face will have exactly the same height and width. So we must consider that the rows and planes of atoms making up a cubic mineral are evenly laid out, all atoms being of the same size.

If we picture atoms as being round like marbles, then they must lie in evenly spaced rows, each marble almost touching four others around it, and the one above and the one below. The point of all this is that when light, vibrating as it does in all directions, strikes such material, the vertical vibrations and the horizontal vibrations will meet the same resistance to their passage through this symmetrical crystal structure. The ray is merely slowed down as it passes through the denser material of the crystal. It is therefore termed *singly refractive.*

No other crystal system has the same regular structure, a structure which offers the same degree of opposition to light's passage, whether vibrating vertically or horizontally. In cubic crystals light will meet the same opposition to its progress regardless of where it strikes or in what direction it travels.

All other crystal systems have some variation from the perfect symmetry of the cube. Light striking such crystals will meet a degree of opposition to its passage that differs for the vertical vibrations and the horizontal vibrations which results in their separation into two rays. The two rays are polarized and vibrate at right angles to each other. The two rays, vibrating in different directions, will be absorbed differently and one ray will travel more slowly.

This division of light into two rays is called *double refraction.*

In mineralogy, a singly refractive mineral is termed *isotropic*, indicating a material having the same properties in all directions. If doubly refractive, it is called *anisotropic.*

Consider the tetragonal system which has three axes, all at right angles to each other. Two axes are the same length, but the vertical axis is shorter or longer than the others. Let us imagine a crystal shaped like a cracker box, standing on its end. It is 4 inches wide. 4 inches thick, and 8 inches high. See Fig. 9-1. If light strikes this crystal on one of its faces where the dimension is 4 x 8 inches, it is evident that the light vibrating vertically will meet a much different structure than will the horizontal vibrations. The result will be a divided ray and double refraction.

Now let us consider what would happen to light striking the end of our cracker-box crystal. It would strike a face 4 x 4 inches. The structure encountered would be the same as on any face of a cube. The vibrations, both

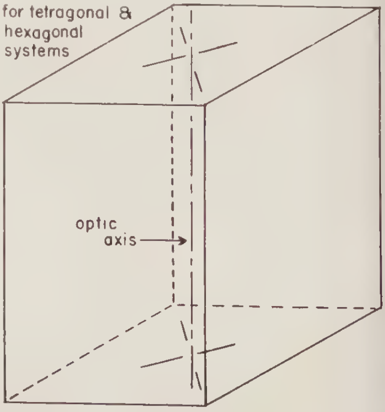


Fig. 9-1

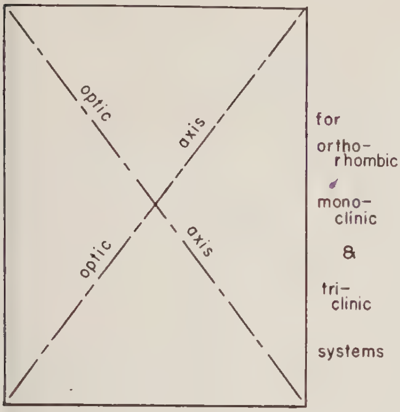


Fig. 9-2

ertical and horizontal, would meet an qual resistance, so there would be no ouble refraction. There would be no olarization, no division of the light ray, this would be a direction of single re-action.

Any direction through a crystal where e light meets an *equal resistance to oth its vertical and horizontal vibra-ons, is a direction of single refraction.*

A direction of single refraction rough a doubly refractive crystal is lled an *optic axis.* Fig. 9-1.

In the cubic system, any direction rough a crystal is a direction of single fraction, so it is called the singly re-active system. Both the tetragonal and xagonal systems have one direction of single refraction, that is the principal crystallographic or "C" axis. Having only one optic axis, they are termed *uniaxial.*

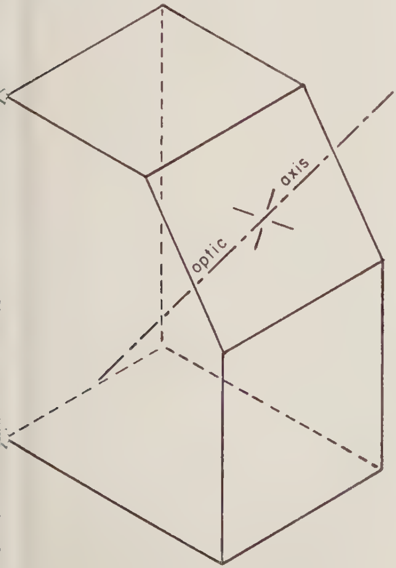


Fig. 9-4

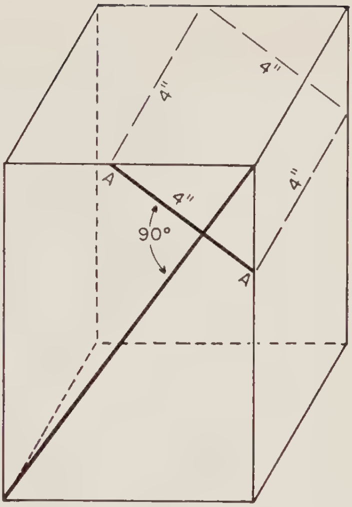


Fig. 9-3

The orthorhombic, monoclinic, and triclinic systems each have two directions of single refraction which cross each other in the center of the crystal. Having two directions of single refraction, and therefore two optic axes, they are said to be *biaxial.* Fig. 9-2.

To explain the positioning of the optic axes in biaxial crystals, let us consider another cracker-box crystal, this time of the orthorhombic system. The orthorhombic system has three axes, all at right angles to each other, but all different lengths. So if our cracker-box crystal has dimensions of 4 x 6 x 8 inches it will do nicely. (Refer to Figs. 9-3, 9-4 and 9-5.)

Remember the requirement for an optic axis — the light striking the crystal in the direction of the axis must meet an equal optical resistance for both the vertical and horizontal vibrations.

Measure and mark diagonally across the upper right-hand corner of the cracker box crystal, a line exactly 4 inches long and at right angles to the diagonal of the face. See A-A, Fig 9-3. Mark the back of the box to correspond to the front, and cut off the corner. This will give a "cleaved" corner the face of which will be exactly 4 inches square. At right angles to this "cleaved"

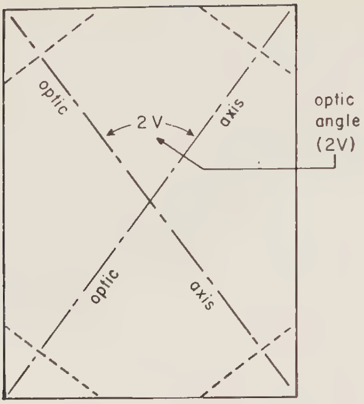


Fig. 9-5

surface, and straight through the center of the crystal, will be the optic axis, the direction of single refraction. Figures 9-3 and 9-4. Of course, the other two diagonally opposite corners could be treated similarly, and so there are two optic axes crossing each other in the center of the crystal. See Fig. 9-5.

In using the term *optic axis*, it is important to know that it is not a fixed line in any particular part or position in a crystal, but is *a direction only*. The phrases, "parallel to the optic axis," and "in the direction of the optic axis," are often used. They mean the same thing —a direction of single refraction in a doubly refractive mineral.

In the biaxial crystal systems, orthorhombic, monoclinic, and triclinic, the relative lengths and angular relation of the axes vary in different mineral species. The optic angle (2V angle) varies from quite small to 90 degrees in different species and because of this variation, may be useful in identification. The determination of the 2V angle is an advanced mineralogical method seldom used in gemology.

BIREFRINGENCE TABLE

Of the more common minerals.

Apatite	.004	Beryllonite	.010
Beryl	.006	Spodumene	.015
Corundum	.008	Tourmaline	.020
Topaz	.008	Peridot	.038
Orthoclase	.008	Zircon	.059
Chrysoberyl	.009	Calcite	.172
Andalusite	.009	Smithsonite	.228
Quartz	.009	Syn. Rutile	.287

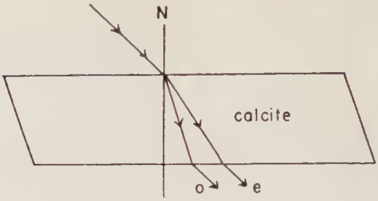


Fig. 9-6
What happens to light passing through a mineral with double refraction.

Birefringence

When light is divided upon entering a doubly refractive mineral, the degree of separation of the two rays differs greatly in different mineral species. Since one ray is bent more and will travel faster than the other, each will have a different refractive index (R.I.). Subtraction of the lower from the higher R.I. gives the *birefringence* which is a measure of the strength of the double refraction. See Fig. 9-6.

The mineral tourmaline, crystallizing in the hexagonal system and therefore doubly refractive, has two refractive indices, 1.620 and 1.640. Subtraction gives .020 which is the birefringence of tourmaline.

The birefringence of a mineral is a very useful property in gem identification. Details of its practical use will be given later with identification procedures.

Pleochroism

Pleochroism is an inclusive term covering the two properties, dichroism and trichroism. When light strikes a doubly refractive mineral it is divided, the two rays vibrating in directions at right angles to each other. They are absorbed differently, and therefore travel at different speeds as they pass through the mineral. If the mineral is colored, the light may appear as two different colors when the two parts of the separated ray emerge. This effect is called *dichroism*. Dichroism is displayed by most *uniaxial*, colored minerals.

Some biaxial minerals exhibit a third color and the effect is then called *trichroism*.

To observe pleochroic effects, a dichroscope is used. The dichroscope is a very simple instrument consisting of a rhomb of Iceland spar (optical calcite)

small magnifying lens, and a tubular
ousing. It is rather easily made by
nyone, with little or no machine equip-
ent. The manufactured instrument
osts about $10.

The dichroscope has a small round
ole in one end to which the eye is
oplied. At the object-end, the small hole
rectangular. This end is held quite
ose to the mineral to be observed. The
ineral must be transparent to some
egree, enough to allow a visible amount
light to pass. Light must come
rough the mineral, not just be re-
ected from its surface, or no change
ill be seen.

To use, hold the object-end of the
chroscope close to the stone or min-
al, the eye close to the opposite end.
double image of the rectangular hole
ill be seen. Rotate the dichroscope and
serve for different colors or different
ades of the same color in the windows.
or example, if two colors are seen, per-
ps light blue and a darker blue,
uble refraction is proved, a big step
ward identification. More complete
tails of the dichroscope's use will be
ven later.

Only two colors are visible through
iaxial stones but even if the stone is
ongly trichroic, only two colors are
ible at one time. With trichroic stones
o colors may be seen, the stone turned
d observed from a different direction, after which one of the previous colors and a third color will be seen.

Dichroic colors may also be seen with a polariscope. With a polariscope, only one color is seen at a time and the stone must be turned to observe further colors. To use the polariscope for this purpose, remove the top polaroid or turn it to the lightest position, hold the stone over the lower polaroid and turn the stone, observing for slight color changes. It works very well but is not quite as sensitive as the dichroscope for finding slight differences of color, where the two colors are seen simultaneously side by side.

The strength or distinctness of the pleochroic colors, as seen, is described by the words: very strong, strong, distinct, weak, and very weak; abbreviated as: VS, S, D, W, VW. For example, the mineral ruby is: dichroic, colors (S), violetish-red, and orangy-red. The mineral iolite is trichroic, colors (VS), colorless to yellow, blue, and dark blue. If a biaxial mineral shows only two colors, it is called dichroic.

To show dichroism, a mineral must be doubly refractive and colored. To show trichroism, it must be doubly refractive, colored, and biaxial.

Singly refractive minerals or materials showing no birefringence show no pleochroism.

Chapter 10

Optical Phenomena

To many, the most beautiful and interesting of gem stones are those displaying some form of optical phenomena. Who could fail to admire a fine star sapphire or a chrysoberyl cat's-eye? Beautiful? Yes, indeed. Expensive? Yes, indeed!

There are many varieties of phenomenal gem stones and not all are expensive. Star sapphire, star ruby, and chrysoberyl cat's-eye are prestige stones, like diamonds and sometimes, perhaps, in better taste. A 10-carat star ruby of best color and appearance might cost from $1500 to $2500 *per carat.* A 10-carat star sapphire of the valued violetish-blue color, with a fine star, will cost $1000 to $1200 per carat. The best quality chrysoberyl cat's-eye of 10 carats costs about $800 to $1400 per carat. Other phenomenal stones are not as expensive. Many are available for a few dollars per stone, although black opal, with fine play of color, has sold for $500 to $800 per carat.

In this chapter we will describe and explain the various types of phenomena including: asterism, chatoyancy, adularescence, aventurescence, labradorescence, orient, girasol, schiller, iridescence, play of color, and interference of light.

Perhaps we should explain the meaning of the word phenomena (phenomenon—singular, phenomena—plural) as applied to gem stones. One of several definitions in the dictionary, "An exceptional thing or occurrence," comes close to the use of the word in gemology. Shipley's Dictionary of Gems and Gemology, says, "An optical effect in visible light occurring in certain, but not all, specimens of a species."

Therefore, star sapphires are considered phenomenal stones, as many specimens of the variety do not exhibit a star. Conversely, alexandrite (a variety of chrysoberyl), although it has a change of color from green in daylight to red in incandescent light which is almost unique among gemstones, is not a phenomenal stone because the effect is common to all alexandrites. They would not be alexandrites without the color change.

We will first consider interference of light as a phenomenon as it is the cause of the phenomena in several varieties of gem stones. To understand this, recall Chapter 7, which explained something of light propagation. Also Chapter 8 on reflection and refraction of light. It would be well to review these chapters.

According to the undulatory theory, light travels with a wave-like motion. From any point on a wave to a similar point on the next wave is called a wave length. If a wave starts at zero, rises to maximum in one direction, falls to zero and rises to maximum in the opposite direction, and falls to zero again, this cycle is one wave length. The height to which the wave rises in either direction is called the *amplitude* or strength of the light wave. This is shown in Fig. 10-1.

If two waves having the same wave length start at the same time, they will reinforce each other, rise to greater amplitude and make a stronger light wave. But, if they start at different points or at different times, so that one wave is at maximum in one direction while the second wave is at maximum in the opposite direction, they are said

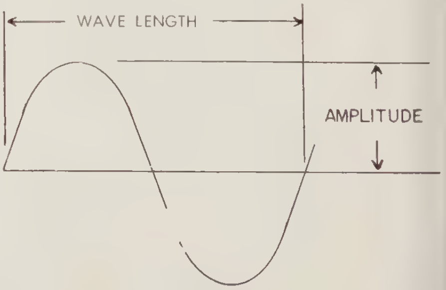


Fig. 10-1

o be *out of phase* and they will work gainst each other and cancel out. The egree to which the waves are out of hase is the degree to which the waves ppose each other. See Figs. 10-2 and 0-3. If the waves are in step they assist ach other, and we get an increase of ght. If they are out of step they may ay be partially or completely de- royed, and they are said to have *inter-* *red* with each other.

Remember, white light is made up of combination of all wave lengths of isible light. When such light strikes a aterial that in some way retards or ssists certain of the wave lengths, some ill be destroyed and others will be in- nsified. This may cause visible color otherwise colorless or black material. ust how this often occurs will be under- ood after careful consideration of Fig.)-4.

Interference of light occurs when light rikes a very thin transparent material, ch as a film of oil on water, or a soap bble. Consider the surfaces A and B Fig. 10-4 to be the outer and inner rfaces of a soap bubble. Light ray 1, riking surface A, is in part directly flected as ray la, and partially re- acted into the material until it strikes e inner surface B where it is re- ected back to surface A and out as y lb.

So far there is simple reflection and fraction, nothing unusual has occur- d.

But follow ray 2 which goes through e same process. It strikes surface A, partially reflected to become ray 2a, here it follows the path of ray lb. It now out of step with lb because lb as travelled through the material and en reflected from the inner surface. t this point where the two waves travel gether, they may be in or out of step, d will assist or cancel each other, ac- rding to their wave length (color) d the thickness of the material A-B.

Can you begin to see why interference light through microscopically thin aterials may intensify some colors and iminate others? The blue may be in- nsified and red or other colors elimi- ted. Or the reverse of this may occur. e effect can be much more complex

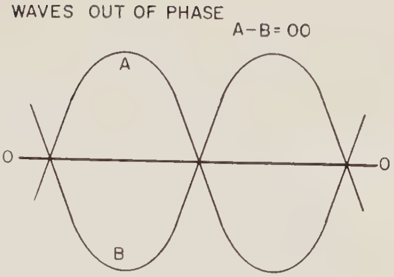


Fig. 10-2

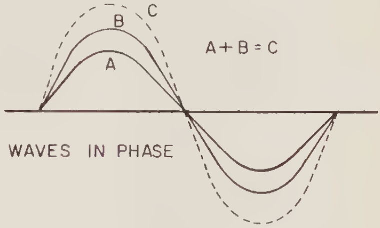


Fig. 10-3

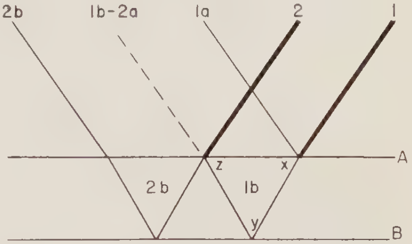


Fig. 10-4

Interference, how it works. In the drawing, the two heavy lines 1 and 2, represent two light rays traveling toward the thin film AB. They are in phase with each other. Ray 1 hits A at x. Part of it is reflected away to la. The balance is refracted into AB and travels around the triangle xyz (by reflection) where it emerges into the air again at z. Ray 2, which is in phase with ray 1, hits AB at z, the point where ray 1b is emerging. Part of it is reflected back to 2a and the balance, like ray 1, is refracted into AB and eventually emerges toward 2b. Now, if AB is about one-quarter of a wave length thick, the ray 1b will travel approximately one-half a wave length going from x to y to z and it will arrive at z out of phase with ray 2 and ray 2a, the reflected portion of ray 2. Because 1b and 2a are out of phase as they travel along their common course from z to 1b-2a, they will cancel each other and there will be no effective light visibly reflected from point z. They are said to "interfere." See Fig. 10-2. If on the other hand, AB was a half-wave length thick, the ray 1b would arrive at z in phase with 2a and the resultant combination of the two "in phase" rays would be a ray approximately twice as bright as either 1a or 2b. See Fig. 10-3.

than the drawings indicate since an infinite number of rays strike the surface to be reflected or refracted, assist or destroy, resulting in a very complex wave structure.

This effect occurs not only when light strikes oil films and soap bubbles, but also when it strikes the surface of many gem materials made up of thin plates or minerals built up by repeated twinning.

It will be readily seen that for a given thickness of material A-B, certain wave lengths (colors) will be emphasized and others weakened or eliminated. This is the cause of the broad flashes of color seen in labradorite.

Labradorescence

Of the feldspars, labradorite of the opaque type almost inveriably displays blanket-like flashes of color, commonly blue — more rarely green — caused by interference of light through its thin layers. This phenomenon is called *change of color* or *labradorescence*. Transparent labradorite never displays such colors. Do not confuse this change of color with play of color in opal.

Iridescence

Another phenomenon caused by interference of light is *iridescence*, a delicate display of colors caused by air-filled cracks or fissures in quartz. When this occurs to a notable extent, the material is called iris quartz (not iris agate).

Play of Color in Opal

Play of color in opal is one of the finest and most beautiful of phenomena in gemstones. Black and white opal from Australia, and some from Nevada and Mexico, may display areas of bright, flashing colors. The cause of this play of color has been popularly accepted as intereference of light across minute cracks that may have occurred in the opal at some point during its process of formation or solidification. The cracks or fissures may have been filled at some later time with material of slightly differing refractive indexes.

This theory, now over 150 years old, has recently come into considerable doubt following research by Sir C. V. Raman, of the Indian Academy of Science, and some original thinking by G. F. Leechman, F.G.A., of Australia.

Opal has been considered as a completely amorphous mineral, but Leechman says this is true only of the lower types such as common opal; that the color of precious opal is the result of interference of light across an "incipient lattice structure," which probably means incipient crystallization. He has found microscopic evidence of "film-pack" layers or areas of crystobalite (a crystalline silica mineral) which appears to offer logical cause for the color in precious opal.

This play of color in opal must not be confused with "change of color," a term applied to the blue or green phenomenal color seen in labradorite. It also has no relation to the color variations caused by dispersion, often called "fire."

The word fire when used in connection with opal is often an ambiguous one. If an Australian opal displays a full play of color with a considerable red component, it might be spoken of as "fiery," but it would not be a fire opal. The term fire opal is properly applied only to opal of a reddish or red-orange color, *without* play of color. This type is also called cherry opal or Mexican opal.

Chatoyancy

Cat's-eye gems are always cut en cabochon to reveal and emphasize the streak of light across the top of the stone. The light streak, sometimes almost white, shading off to a rich honey color on the sides, is the indication of a chrysoberyl cat's-eye. In the jewelry trade it is often called precious cat's-eye, oriental cat's-eye, or just plain cat's-eye.

Several other gem minerals occasionally occur with the necessary inclusions to cause this phenomenon, such as quartz, tourmaline, and orthoclase, but if the name cat's-eye alone is used, it indicates chrysoberyl cat's-eye. Minerals other than chrysoberyl should never be called cat's-eye without a prefix to indicate the species.

The chatoyant effect results from reflections from oriented inclusions, very fine tubes or fibres, all running in one direction through the mineral. The chatoyant streak will always appear at right

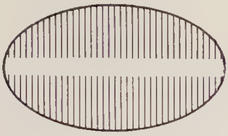


Fig. 10-5

ngles to the direction of the fibers. See Fig. 10-5.

The effect is easily demonstrated by olding a spool of silk thread toward he light. With the thread fibers running from left to right, a fine chatoyant treak will be seen along the length of he spool, at right angles to the threads.

Quartz occasionally occurs with a ine chatoyant effect, perhaps somewhat nore greenish, but in general appearnce it usually lacks the silky transluency of chrysoberyl cat's-eye. The ewelry trade often calls quartz cat's-eye, Hungarian cat's-eye," or "occidental at's-eye." Fine specimens may be very ifficult to distinguish from chrysoberyl at's-eye without scientific tests.

The story is told of a rather expenive cat's-eye necklace owned by a large, ery ethical jewelry store in New York City. Together with other fine jewelry was loaned to a class of New York ewelers studying gemology. After beng thoroughly inspected by many of the tudents, a sharp-eyed young man noted ne stone seemed slightly different in ppearance from the others. He asked ermission to test it and, by refractive ndex, found it to be quartz. The other ones were tested and three more from e total of twelve were found to be uartz.

One might think the jeweler-owner ould have regretted lending the neckce to this class in gemology, but acually this was not so. Being an ethical eweler, and there are many of them, e was glad to find out about the quartz ones before selling the necklace. If e had sold a chrysoberyl cat's-eye neckce with some quartz stones he might ave been subjected to a lawsuit and vere loss of prestige.

The cause of chatoyancy in quartz is e same as in chrysoberyl, parallel bers or tubes which, by reflection, use a band of light at right angles the fibers.

Another variety of quartz displaying a cat's-eye effect is tigereye. Tigereye is a pseudomorphic mineral, a crystalline quartz replacement of fibrous blue asbestos, called crocidolite. When cut with a rather high, almost sharp crown, a very pronounced cat's-eye band results. The color is never that of true chrysoberyl or quartz cat's-eye, but tends toward a gray-brown or greenish gray color. In the jewelry trade these stones are known as "crocidolite." If the material includes some unaltered blue asbestos, giving a tinge of blue, they are called "hawk's-eye."

The cause of the chatoyancy is reflection of light from oriented quartz fibers.

Do not confuse the true quartz cat's-eye with tigereye cat's-eye or "crocidolite." The quartz cat's-eye is always more valuable.

Good tourmaline cat's-eyes are rare. The material from which they are cut is often a fibrous, milky section near the base of the crystal. Since inclusions necessary to cause the cat's-eye run lengthwise, not many crystals have sufficient width for a useful size cabochon.

One tourmaline miner estimated that less than one crystal in a thousand will cut a cat's-eye. The cause of the chatoyancy in tourmaline is reflection of light from oriented hollow channels.

Almost any gem mineral containing sufficient properly oriented inclusions may, when correctly cut, show a good cat's-eye. Blue apatite, orthoclase feldspar, ruby, sapphire, alexandrite, emerald, and others, occasionally turn up with a fine cat's-eye. Of course they quickly find a home in someone's gem collection.

Asterism

Star stones are the aristocrats of phenomenal gems, with star rubies as tops in value. Star stones, like cat's-eyes, must be cut en cabochon to reveal and enhance the rays of the star.

Most star stones display six rays, but of course, there are the less common four-rayed star garnets, and the five-, seven-, or any number to 12-rayed freaks. The cause of these unusual stars will be explained later.

Reflection of light from oriented in-

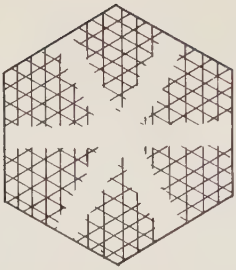


Fig. 10-6

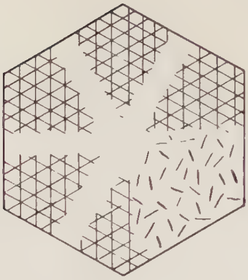


Fig. 10-7

clusions is the cause of the stars, as it is the cause of the phenomenon in cat's-eye stones; the difference is in the type of inclusions and their orientation. Asteriated stones best known to the public are probably star sapphire, ruby, and quartz. All of these minerals crystallize in the hexagonal system and normally have six rays in their stars. Much rarer are asteriated emerald, alexandrite, chrysoberyl, apatite, and orthoclase.

The inclusions which cause the rays are very fine rutile needles, usually termed "silk." Their orientation will be understood from Fig. 10-6 which represents a cross section of a corundum crystal. The needles lie in three groups each of which is parallel to two opposite sides of the hexagon. The rays of the star are always at right angles to the needles which cause them.

If the needles in the mineral are a little sparse or perhaps missing from one section of the hexagon, the ray will also be missing. This explains the freak stars having five or some other odd number of rays. See Fig. 10-7.

The crystal from which a star stone is cut may have been internally twinned, and as the inclusions are oriented according to the crystal structure, the result may be six groups of needles instead of three, each group paralleling two faces of the dodecahedron (double hexagon). This would result in a 12-rayed star. If sufficient needles were missing in some sections, some of the 12 rays would also be missing, causing a freak star.

Several years ago, a newspaper mentioned a fine blue sapphire crystal which, luckily, was cut by a man who quite early in the cutting discovered the 12 rays and did a fine job of orienting the star. It was reported as the finest 12-rayed sapphire known, and was sold to a collector for something over $30,000.00. I do not recall the size.

If asterism occurs in gem minerals crystallizing in the cubic system, their two sets of needle-like or "silk" inclusions will display a four-rayed star. Almandite garnet from Idaho, quite well known to hobbyists, is of this type. The stars are rather vague and stones are more desirable as specimens than for jewelry.

Quartz, a hexagonal mineral, displays a six-rayed star, but usually a faint one. The cause is the same: fine rutile needles or "silk." Rose quartz is the only common asteriated variety. Amateur gem cutters have become quite expert in orienting the stars in this mineral. Some cut it into spheres to locate the position of the star; others have learned to use a polariscope to locate the optic axis which is the center of the star. The use of the polariscope for this purpose will be explained in the chapter pertaining to that instrument.

Adularescence

The moonstone effect, called *adularescence*, is a peculiar sheen, often a floating blue light seen on rounded surfaces of stones cut from certain species of feldspar. Orthoclase is the most common species displaying this phenomenon, but occasional specimens of albite and oligoclase show the effect.

In England, the term opalescence is preferred for this effect. As a possibly confusing term, opalescence is seldom used in this country.

The cause of this phenomenon is generally considered to be reflections from layers of minute, colorless, but very lustrous crystals of kaolin, a decomposed feldspar.

The name given to this phenomenon,

dularescence, is derived from the name f a variety of orthoclase first found the Adular Mountains of Switzer- nd. In gemology, the term adularia, as become synonymous with precious oonstone.

Sometimes the term moonstone is in- rrectly applied to waterworn speci- ens of chalcedony, as "beach moon- ones." Chalcedony, when cut, may ap- roach the translucent appearance of rthoclase moonstone, but will never dis- ay the blue sheen of true moonstone.

Aventurescence

The phenomenon displayed by aven- rine quartz and by aventurine feld- ar (sunstone) is called *aventures- nce.* It is the glittering reflections om inclusions in these minerals.

Aventurine quartz, usually green om inclusions of fuchsite, shows flash- g reflections from inclusions of mica.

Sunstone, also called aventurine feld- ar, is a variety of oligoclase, a species feldspar. The aventurescent appear- ce is a metallic red visible only in rtain directions, caused by reflections om minute inclusions of hematite ori- ted along parallel twinning planes of e mineral.

A man-made glassy material called oldstone" is often spoken of as aven- rine glass. The rather dark brown ass has copper crystal inclusions to ch a degree that it appears a fine glittering, golden color. This material was popular in the early years of this century, dropped out of fashion for many years, but is again rapidly regaining its popularity. It is also made in dark blue, black, and perhaps other colors. Most jewelry stores now carry it in stock. The making of the goldstone is reputed to be a trade secret known only to certain glass factories in Italy.

Schiller, a mineralogical term, is used in gemology to indicate a metallic luster observed in certain directions in the gem minerals bronzite, hypersthene, and diallage. It is generally believed to result from minute inclusions along twinning planes, or layers of negative crystals having a common orientation.

Orient is the name given to the peculiar, subsurface sheen of nacreous pearls. It is caused by interference of light through the outer layers of nacre which cover the pearl.

Girasol, a rather fabulous term, is usually applied to opal but may be used to describe any mineral which exhibits a moving, billowy light across its surface. As applied to opal, it is said to indicate a stone of generally blue appearance, with a billowy red light across its surface. There seems to be nothing definite about the term. It is sometimes applied to minerals, such as girasol sapphire and girasol quartz.

Chapter 11

Color in Gems

Color is that certain sense that tells you a leaf is green, the sky is blue, or a ruby is red. But can you describe these colors to someone else?

Can you tell them just what shade of green the leaf is? Is it a light shade of green, a dark shade of green, or one of the dozens of shades in between.

In Chapters 7 and 8 we explained some of the physical facts about light. The object of this lesson is to explain in a simple way the naming of color, and, we hope, to explain it so one gem enthusiast can talk to another and convey his idea of color to the other.

Various names are given different colors. Some are named after objects, like apple green, olive green, cherry red, etc. Some are named after localities, like Persian blue, Naples yellow.

Then, probably just to sound attractive or different, there are names like dream fluff, wafted feather, and fable. These last three names are just a way of saying purplish white.

Fancy names are used a great deal by companies patronized by women. For instance, a woman would be more apt to buy a coat if it were called mauve wine than if it were called mud purple. In the same vein, desert sand and frost blue are names used by an automobile manufacturer to describe the color of a car. Of course, you wouldn't know what colors they were until you had seen them.

One source lists ninety-one ways to say dark blue. A few of them are cobalt blue, peasant blue, Japan blue, and Bagdad.

Few people are really color conscious or have made a study of color. For this reason not many can describe the exact color of an object to another person. They may say something is red or blue but that is as far as they can go.

Color perception, the ability to judge small color differences, is not shared equally by all people. Generally speaking, women have much keener color perception than men. Younger women usually have better color perception than those of middle age or older (except those older persons who have developed and maintained their ability to judge colors through constant practice).

Almost every kind of business uses color in one form or another — the textile industry, paint companies, auto manufacturers, food, and advertising. Practically everything they use is colored in some way. Without some kind of system to go by these companies would not be able to convey to each other and to their customers the colors of thei products.

For this reason, various color systems or nomenclatures for color are on th market. To name a few: the Ostwald System, Nu-Hue Color System, Munsel System, Plochere Color System, and th Maerz and Paul Dictionary of Color

All of these are excellent for describ ing color in different ways. But to th average person, they are both compli cated and expensive, some costing $15 to $200.

The whole world around us explain things in the language of color. We loo at a plant and immediately our sense o vision tells us the stem is brown, th leaves are green, the petals are purpl The rug on the floor is light brown. Th book you are holding white with blac printing.

Some things we see are pleasing to th eye. If the colors are harmonious w like them. If they are harsh they di please us. In our daily lives we li color; we learn to obey different color When driving a car, everyone know that red means stop, danger; gree means go, safety. Without color, th world would be a dreary place in whic to live.

Color can be compared with musi The more we learn about it, the mo we appreciate it. By knowing color, t beauty of the hills, the sky, flowers, a *rocks* take on a different meaning.

tated before, the purpose of this chapter s to explain color in simple terms.

Color Is Light

To begin with, color is a quality of ght. Without light color cannot exist. ll colors we see are a sensation of viion. Color may be light entering our yes from the sun, a flame, or an electric amp. The color it shows is the reflected ght and not in the object itself.

As an example, a beam of light reected from a blue flower does not pick p the blue color from the flower. The act is that the flower *subtracts* or *abrbs* all the colors from the white light *xcept* blue, and this is the color we see. *his subtraction or absorption is the ey to all color.* Remember this point.

When a beam of white light passes rough a prism it is divided into its mponent colors. If it is projected onto screen we see what is called the specum. See Fig. 8-7.

The main colors of the spectrum are d, orange, yellow, green, blue, and olet. From these colors any other lor can be derived. In pigments the ree *primary colors*, red, yellow, and ue, are colors that cannot be made p from a mixture of any other colors. ut all other colors can be made by ixing the three primaries.

Secondary colors are ones that can made by an equal mixture of two imaries.

Mixing Colors

The three primary colors, red, yellow, d blue, when mixed together in pure, ual proportions, will produce black. the colors are thin, or not of equal ength when mixed, the result will be ay or brownish. Colors that cancel t or neutralize each other are called utral colors. Black, gray, and white neutral colors.

Mixing the primary colors, for exame, blue and red, will produce purple. d and yellow make orange. Yellow d blue will make green. These are lled secondary colors.

Following the same idea, we will mix ue with orange, a primary with a condary. As stated above, orange is mixture of red and yellow, so we ve our three primaries mixed together again and the result is black. By the same reasoning, yellow and purple, or green and red, will produce a black.

To go a little farther, if we mix two secondary colors together, say green and orange, we will have all three primary colors but not in equal proportions. Green is half blue and half yellow, while orange is half red and half yellow. This makes the mixture one quarter blue, one quarter red, and half yellow. This is not enough to completely neutralize these colors so, with a preponderance of yellow, the result is a yellowish brown. This kind of color is called a *tertiary color.*

Color Characteristics

To be able to describe the color of something properly, three characteristics or properties are used. These are *hue, tone,* and *intensity.* These are sometimes called the three dimensions of a color.

Some years ago these terms were selected by the Gemological Institute of America and are now used by gemologists everywhere.

The *hue* of a color is its basic color identity. Red, yellow, and green are hues, or any intermediate colors such as red-orange or blue-green. Hue is a term applied to all colors except black, gray, and white.

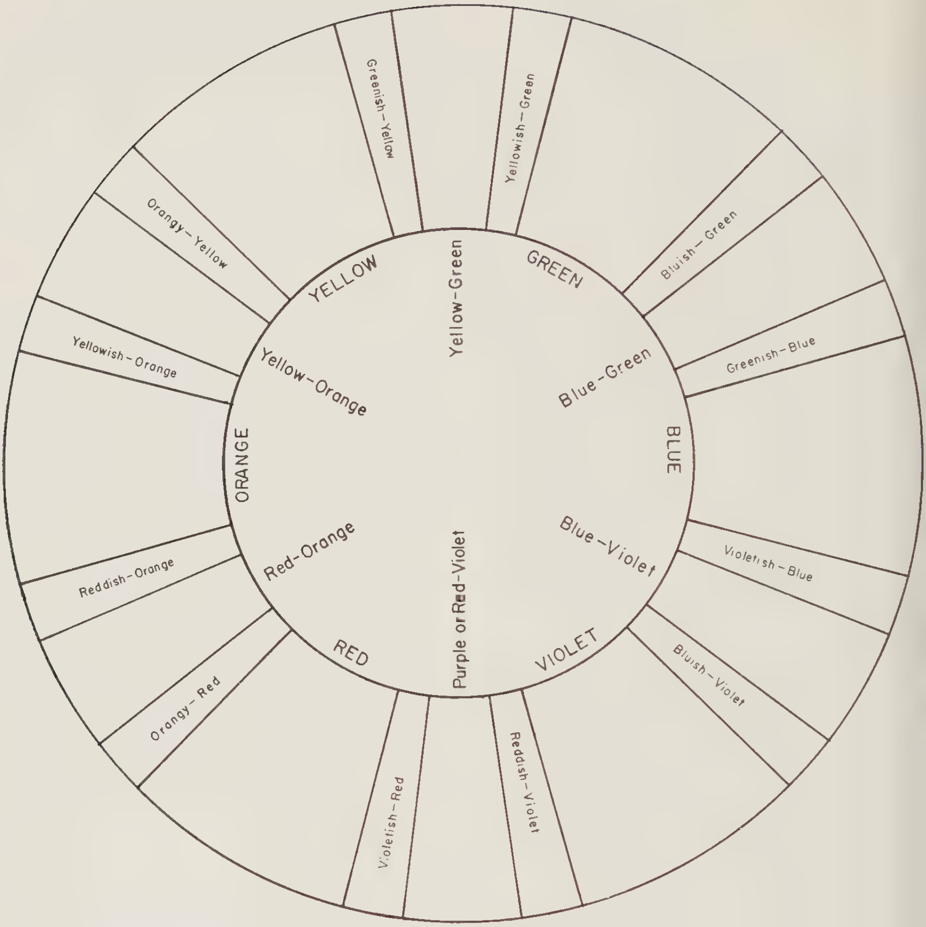
Tone is the lightness or darkness of a color. In other words, the amount of white light it seems to reflect. The addition of white to a color will make it a lighter tone; black will make it a darker tone. Examples are light blue, and dark blue.

The third property is *intensity* or the degree that a color is vivid or dull—or the degree of its freedom from any neutralizing factors.

Hue

The easiest and most convenient way to learn color is by the use of a color circle. See the printed color circle. This "wheel" is called a *subtractive color circle* because all colors are subtracted from white light except the color we see. This circle is patterned after some of the color circles now on the market. It is sectioned on the six principal hues. These are the wide sections — red, orange, yellow, green, blue, and violet.

Half-way between the principal hues, is one composed of each adjacent hue.



Instructions for Coloring Color Chart — Use Crayola crayons, Binney & Smith, No. 242.

Chart Color	Crayola	Chart Color	Crayola
Violet	Violet	Yellow	Yellow
Red Violet	Light Magenta	Yellow Green	Yellow Green
Red	Red	Green	Green
Red Orange	Red Orange	Blue Green	Middle Blue Green
Orange	Orange	Blue	Blue
Yellow Orange	Yellow Orange	Blue Violet	Blue Violet

Between red and orange is one called red-orange. This is a mixture of half red and half orange. Between orange and yellow is yellow-orange, and the same around the circle. This gives twelve hues on the circle.

Upon occasion it may be necessary to indicate smaller color differences than are possible with the twelve hues mentioned. Quarter colors may be placed between the half-colors making three colors between the six principal hues as shown on the chart.

It has been said that there are over a million different hues. In fact, som coral dealers in Italy make a distinctio of one hundred color grades in cora from red to very pale pink. This i getting it down pretty fine.

Do It Yourself

The color circle, as it appears, is i black and white, lettered where eac color should be. We could not print thi in color but it is our idea that eac reader can color his own chart. In thi way he will be actually putting the color in proper sequence and learning as h does.

After experimenting with various coloring agents, it was found that the common crayons called *Crayolas* approximated the colors needed. The Crayola box No. 242, made by Binney and Smith, may be purchased in any 5c & 10c store. It contains the six principal hues plus the half-hues such as blue-green, red-orange, but the other colors are not satisfactory for the quarter color, e.g. greenish blue.

We realize that these will not be exactly true colors, if compared with he expensive color charts on the market, but they will be very close and in most respects will serve as well. The main hing is that you will know the names of he colors and approximately how they hould look.

Tone

This takes care of the hues, now as to *tone*. The printed scale of tone is from white to black, with tones between of very light, light, medium, dark, and very dark. By using this scale, a hue can be said, for instance, to be very light blue or medium blue.

The chart is in black and white as this is the only "color" we can present. However, you can substitute any color for the black. The tone of the color will then become lighter as you add white to it, the black representing the darkest possible condition under which you can encounter the particular color.

TONE SCALE

Thus, a so called navy blue might be termed dark blue, but still basically blue (the hue). If you start to add white to the dark blue it will get lighter and lighter as more and more white is added. Finally you will have a very light blue (almost white).

The same procedure can be followed with any other hue, taking the darkest possible tone for the very dark and then adding white until you arrive at an "almost white" with only a hint of the original color. In all these changes the basic hue does not change. If you start with a dark yellow-green, as you add white you will get a lighter tone but it will still be basically yellow-green regardless of how light it gets. The variation will be in tone only, not hue.

Intensity

The third term used to describe color is *intensity*, a term very hard to describe in words. Intensity varies similarly to tone, that is, from high to low. It is often confused with tone but is entirely different.

Intensity is the degree of color brightness that is apparent when a particular color is seen by reflected light (as all things are usually seen). The most common current example of this is the difference between ordinary show-card colors (paints) and the new fluorescent paints used for sign painting. Take the red, for instance. Both paints can be the same hue (red) and the same tone (medium) but one will seem much brighter and more vivid than the other. It will, in fact, be brighter because it is reflecting more light. The fluorescent paint will be the brighter and therefore the more intense. Its intensity would be said to be very high.

Again, our chart can only show intensity in terms of black and white, the white being the most intense as it reflects the most light, the black being the least intense with less reflection of light.

Again substituting color for the black and white (or coloring the chart with one of the Crayola colors) you will see that the intensity of the color gets lower as the black end of the chart is approached and the color diluted more and more with the gray.

Generally speaking, pure colors are the most intense. As gray or black are added as a neutralizing agent the intensity is lowered without changing the hue. (A true change in intensity can be made without changing either the hue or the tone, but in practice this is seldom the case as colors are seldom pure and adding a neutral color to any hue to lower the intensity will usually darken the tone, too.)

Using Color Names

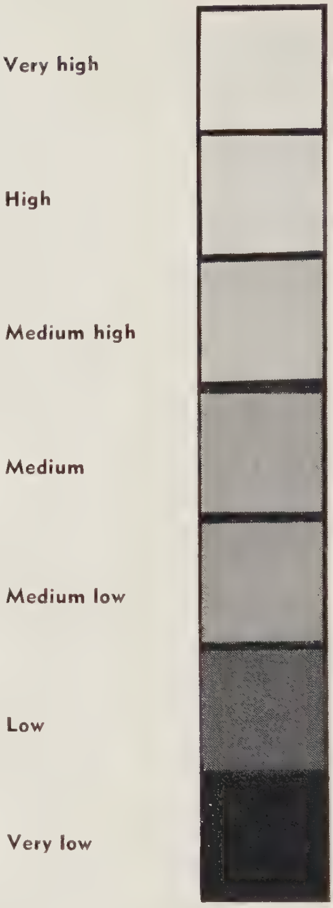
If by now you have your chart colored and have studied the tone and intensity scales, we can start to name the color of an object. Suppose you get the nice looking rock you found on your last field trip. First the hue. It is red. Second the tone. It is very light. So that makes it a very light red. Now the intensity. The color is vivid, so it would be spoken of as high intensity. Put these all together and your rock is a very light red of high intensity. It might be a pink sapphire or a pink tourmaline. If it were morganite, it would probably have a small amount of purple in the very light red. It would therefore be a very light red purple. Easy!

Pick out some more rocks and practice the same system of naming the color. Before long you will be naming the color as easily as you say the name of the rock.

Before leaving the subject of color we will mention a subject of special interest to the ladies, color harmony and contrast.

Color harmony is merely an arrangement of colors that gives a pleasing effect. Of course, personal taste enters largely into this. But, if we consider the color circle, we may say that adjacent colors on the circle are harmonious, such as green and yellow, or yellow and orange. But not yellow and red, or yellow and purple. They are too far apart on the color circle.

INTENSITY SCALE



Color contrasts are those on opposite sides of the circle. If properly used they tend to accent a given color. For instance, if a lady's dress were yellow and purple it would probably appear unpleasant. But, if it were entirely of yellow, a flower or a brightly enamelled pin of purple would be a very pleasing contrast. This would accent the yellow. This is color contrast.

For those desiring more information on color, the following books are suggested: KODAK DATA BOOK — "Color, as Seen and Photographed." AN INTRODUCTION TO COLOR, by Ralph M. Evans, Eastman Kodak Co. Both are available at camera shops.

hapter 12

nclusions in Gem Stones

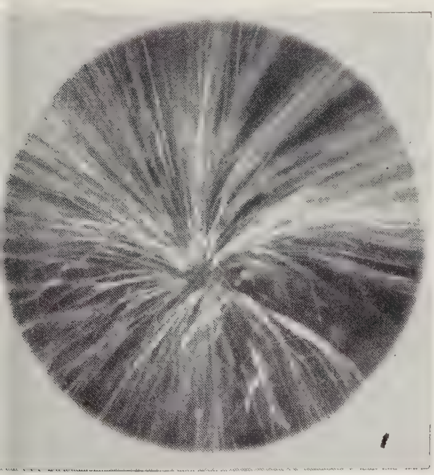
The subject of inclusions seems of ore than normal interest and certainly s a "must" in the study of gemology.

A great deal of our modern ideas and nformation about gem stone inclusions as resulted from the research of Ed-ard J. Gubelin, Ph.D., C.G., F.G.A., of witzerland. Gemology acknowledges im as the greatest authority on the ubject. His book, "*Inclusions as a eans of Gemstone Identification*," pub-shed by the Gemological Institute of merica, is now the standard reference ork on the subject.

The photomicrographs with this chap-r were photographed through one arrel of a binocular, gemological, Gemolite" type, Bausch and Lomb mi-roscope. A 35mm Exakta VX camera as used. The best ones were made on anatomic X film.

Some will wonder about the light and ark streaks that cross the background f some pictures. They are out-of-focus ack facets of the stone photographed. hey have nothing to do with the in-usions. Just ignore them.

The dictionary defines an inclusion as ny foreign body, solid, liquid, or gaseous, enclosed in the mass of a mineral. Gemology goes a little farther and includes cleavage cracks, fractures, growth lines, and color zoning.



g. 12-1. DEMANTOID. 30X. Byssolite, irlike asbestos inclusions called "horse-ils."

It is sometimes difficult to separate, in the mind of the average person, the word "inclusions," from the more derogatory words "imperfections" and "flaws." The latter terms are often used in the highly competitive diamond trade but infrequently with reference to what the jewelry trade calls "colored stones" (any gem stone other than diamond, colored or colorless).

It is interesting and highly instructive to note the complete change of terms and tactics used by an experienced jewelry salesman when his prospective customer changes his interest from diamond to emerald! When selling diamond, good merchandise must be either "perfect" or "flawless." But emerald. That is different! The inclusions, often so large and numerous as to darken and obscure the interior of the stone, are then called *jardin* (garden), and are spoken of with great respect and with bated breath. Well, perhaps it is like pink corundum—which may be called sapphire or ruby, depending on whether one is buying or selling.

But inclusions can be a very interesting and informative subject when investigated by a good crystallographer or a top-flight scientist-gemologist, such as Dr. Gubelin.

Inclusions may be divided in two different ways: (1) as to type of material of which formed: *solid, liquid, or gaseous;* (2) by the period of their formation as related to that of the crystal surrounding them. The latter system divides inclusions into: *pre-existing, contemporary,* and *postformed.*

Pre-existing inclusions are of necessity some solid form of matter, often crystals of the same or different composition from the crystal which grew around it. An example of pre-existing inclusion is

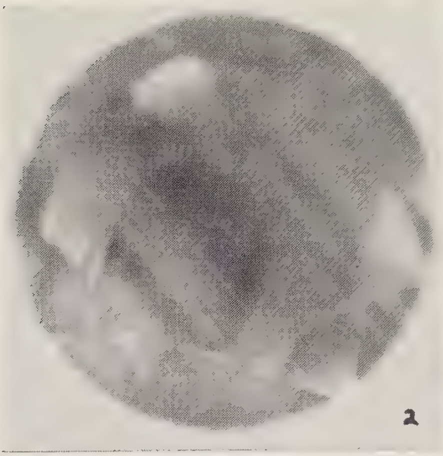


Fig. 12-2. SAPPHIRE. 30X. Fine rutile needles oriented at 60 and 120 degrees, called "silk."

Fig. 12-3. SAPPHIRE. Same as Fig. 12-2.

the so called "horsetail" inclusions found in demantoid. Fig. 12-1. These inclusions are byssolite, a hairlike form of asbestos, and one of the few really distinctive inclusions, offering conclusive proof of the gem's identity. Preexisting inclusions also may be of amorphous or earthy materials.

Inclusions formed at the same time, from the same mother liquid or gas, are called contemporary inclusions. They may have been formed from the same solution or from gases or solutions which were nonmiscible with that solution. Most of the "silk" and needlelike oriented inclusions are of this type, Figs. 12-2 and 12-3, as are most liquid inclusions, Fig. 12-4, and many of the type of inclusions termed euhedral (crystals completely bounded by well developed faces).

Postformed inclusions are formed, after crystallization of the parent crystal, from gases or solutions enclosed during the formation of the crystal. Very slow cooling over a prolonged period may permit crystallization of such included materials, or their combining with the elements of the parent crystal. Of this type are the liquid filled cavities in topaz, Fig. 12-5, and the well known three-phase inclusions in natural emerald, Fig. 12-6.

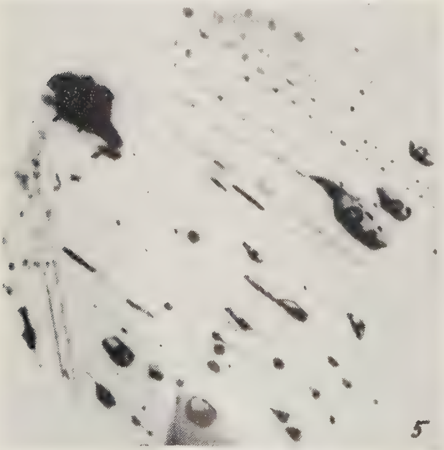


Fig. 12-5. TOPAZ. 75X. Drop-shaped, liquid-filled cavities with bubbles of gas. Called two-phase inclusions. Found in other species.

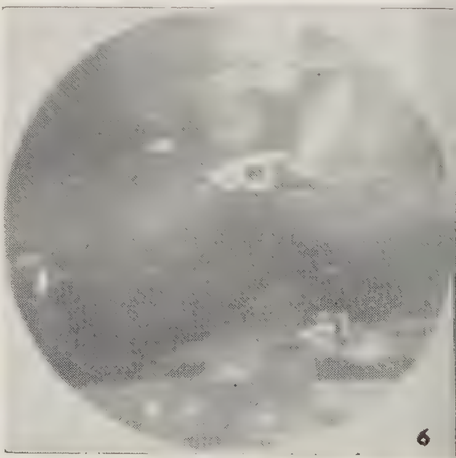
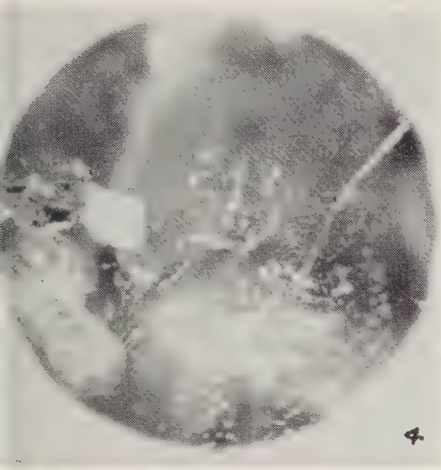


Fig. 12-6. EMERALD. 75X. Liquid-filled cavities with bubbles of gas and a solid crystal of halite. Three-phase inclusions. Seen only in natural emerald from Colombia



ig. 12-4. SAPPHIRE. 30X. Crystals and quid-filled inclusions.

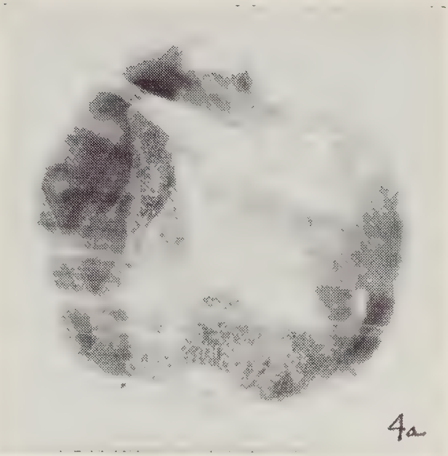
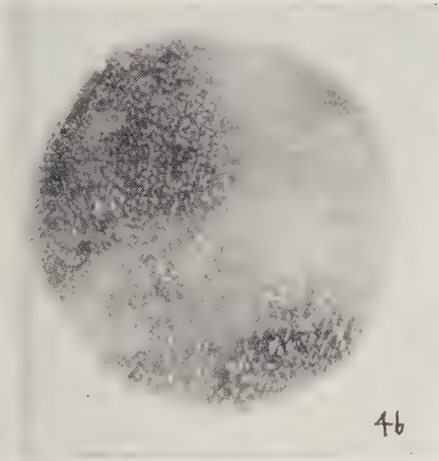


Fig. 12-4a. Fingerprint inclusions in sapphire. 10X. Note also oriented needles.



g. 12-4b. Same as Fig. 12-4a except 30X.

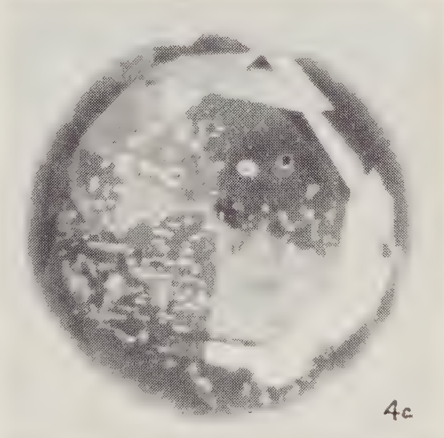
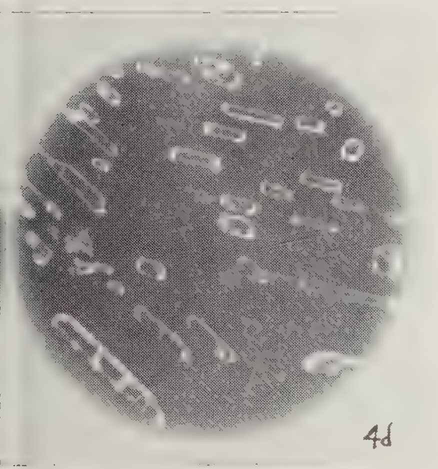


Fig. 12-4c. Liquid-filled inclusions in sapphire. 10X.



g. 12-4d. Same as Fig. 12-4c except 30X.

Fig. 12-4e. Same as Fig. 12-4c except 75X.

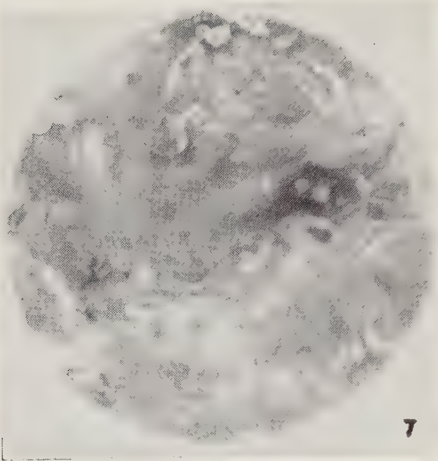


Fig. 12-7. HESSONITE. 30X. Diopside crystals of low relief, and "heat-wave" effect. Characteristic of hessonite.

Another cause of postformed inclusions is the entering of external liquids into cracks or imperfections in the crystal structure, which may later continue to grow sufficiently to seal the cracks. Under the microscope, such liquid inclusions often appear as "feathers," or along curved planes, looking much like an air view of the closely spaced lakes in Minnesota. They occur in beryl, topaz, moonstone, corundum, garnet, quartz, synthetic emerald, and possibly many others.

The word *relief* will be used frequently in describing an inclusion. Relief is the relative visibility of the inclusion as compared with the surrounding mass. The relief of an inclusion depends upon the color contrast and refractive index of the materials. The greater the difference in R.I., the higher the relief. The stubby crystals often seen in hessonite garnet, Fig. 12-7, because they are almost invisible, are said to be of low relief.

Inclusions of the solid type are most frequently of a crystalline nature. Their appearance, in so far as it will aid identification of the parent crystal, is more important than identification of the inclusion. Such inclusions may be the same as the surrounding crystal but differently oriented, or they may be of an entirely different nature.

The most common of the crystalline inclusions are: coarse or fine rutile needles, zircon crystals, needles or blades of actinolite, and chlorite. The last two often combine to closely simulate flowers or other fairyland flora in quartz. Fig. 12-8. Also sections of mica, calcite, crystals of quartz, spinel octahedra, garnet crystals, and asbestos fibers are frequently encountered.

Among the most interesting of inclusions, possibly because of their wide range of appearance, are the liquid inclusions. They may be cavities filled with the solution, or some part of the solution from which the crystal grew, such as carbonic acid, a water solution, or a completely foreign liquid.

The voids or cavities may result from irregularities in the crystal's growth,

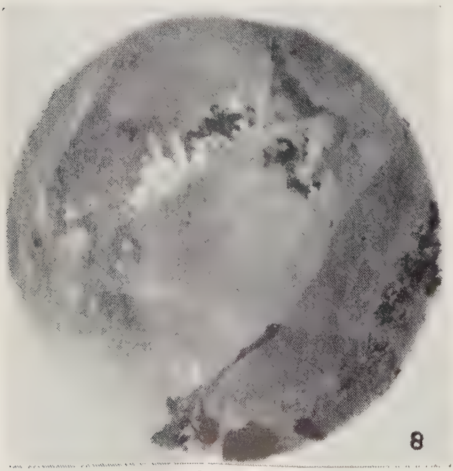


Fig. 12-8. ROCK CRYSTAL. 10X. Vertical actinolite rods topped with chlorite.

Fig. 12-9. SAPPHIRE. 30X. Shrublik liquid and clay-filled inclusions.

10

Fig. 12-10. QUARTZ. 30X. Oriented negative crystals, sometimes filled with liquid and a gas bubble. Common to several varieties of quartz.

e crystal growing around and enclos- g the "cyst" of liquid. Or the crystal ay fracture or cleave, allowing liquid penetrate and, later the crystal may row over and through the crack, Fig. 2-9, sealing and separating the liquid to tiny liquid-filled inclusions. The fingerprint" type of inclusion is formed this way.

When growing around such impurities s liquids, those minerals with a very rong tendency toward crystallization, ill maintain their rows and planes of oms, as best they can, as they cover e foreign matter, making a geometri- lly shaped cavity. Such cavities are lled *negative crystals.* Fig. 12-10.

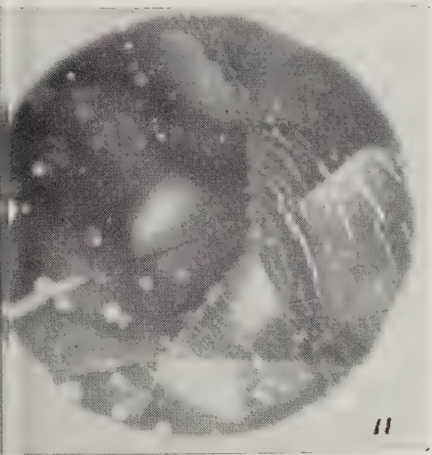
Negative crystals are always formed such directions as to become an ori- ted part of the crystal structure.

Negative crystals or irregular cavities equently contain both liquid and gas. the gas forming a bubble in the liquid of proper proportions, it will move om end to end of the liquid, like the bble in a carpenter's spirit level. Ame- yst and rock crystal quartz frequently ow this type of inclusion, as in Figs. -5 and 12-10. They are called *two- ase inclusions.*

The most interesting of the liquid- led inclusions are those where cavities ntain more than one liquid. Two or ore nonmiscible liquids in the same vity, sufficiently different in R.I. to ve them a different degree of relief, make a very distinctive inclusion. Such inclusions are most frequently found in topaz, but Dr. Gubelin says they may be found in almost all gem minerals.

As a rule, gaseous inclusions or gas bubbles mean man-made glass or synthetic gem materials. Like most rules there are some notable exceptions. The natural glasses, moldavite and obsidian, usually contain a few and may contain many gas bubbles. Hyalite opal may contain gas bubbles.

In any synthetic gem, other than emerald, spherical gas bubbles may be found. Figs. 12-11 and 12-12.



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. 12-11. SYN. RUBY. 30X. Spherical ; bubbles are proof. Fast-polish checks on et surfaces are indications of ruby's syn- itic origin.

12

Fig. 12-12. SYN. RUBY. 30X. Curved striae, nearly straight, near top. Large cloud of spherical gas bubbles, bottom. In upper left, large bubbles joined in knobby groups.

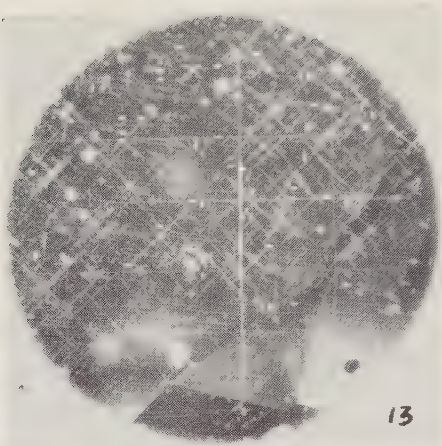


Fig. 12-13. GARNET and GLASS DOUBLET. 30X. Spherical air bubbles on junction plane, oriented needles in thin garnet top.

Assembled stones (doublets and triplets) almost always show gas bubbles at the plane of junction between the parts, where they are fused or cemented together. Fig. 12-13. Bubbles oriented on a single plane make the identification of assembled stones easy.

Man-made glass, called "paste" in the jewelry trade, usually contains some gas bubbles. Not always spherical, they may have been stretched as the glass was pulled or worked, and the appearance is then almost like tubes but with smooth sides and rounded or sharp ends. About 20 per cent of glass gems will be found quite clear without inclusions or swirl marks. See swirls in Fig. 12-14.

Fig. 12-15. SAPPHIRE. 10X. Color zoning in blue sapphire from Ceylon.

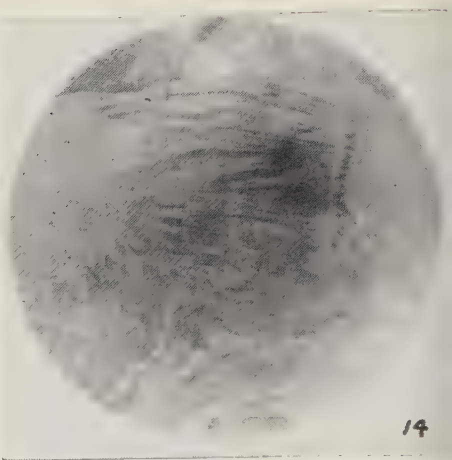


Fig. 12-14. GLASS. 10X. Unusually pronounced swirl marks.

Also considered as inclusions are internal fractures and cleavage cracks. When filled with liquid, such inclusions may appear to some extent like feathers or insects' wings. At other times the distribution of the liquid may make a very natural appearing "fingerprint."

Color zoning is due to an unequa supply of coloring oxides in the mothe liquid during the crystal's growth Quartz, corundum, and tourmaline ofte show this peculiarity. Fig 12-15.

Sediments, coarse or fine, may settl on the surface of crystals during growt or during periods of arrested growth These are the cause of the rather com

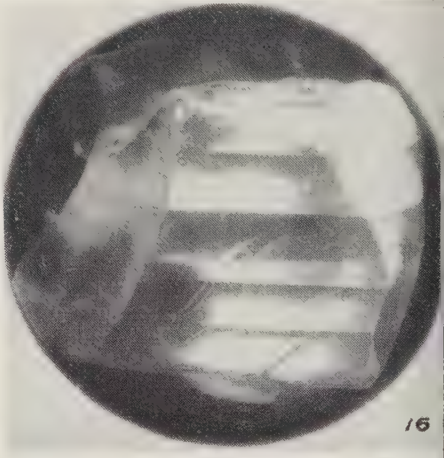


Fig. 12-16. FELDSPAR. 10X. Twinn sectioning observed in polarized light. Com mon to several species of feldspar. Not v ible in nonpolarized light. Does not un mineral for cutting.

ion "phantom" crystals seen in larger rystals, as well as most of the straight riae or visible growth lines seen in ems.

Twinned parts of a crystal, called *minae,* often cause a noticeable sec- oned appearance in gems. See Fig. 2-16. This effect is most easily seen hen the stone is examined in the olariscope. Corundum, quartz (citrine nd amethyst), and several of the feld- oars are frequently found with this type f inclusion. In quartz the effect is ıused by a shifting of crystal layers ather than twinning. Fig 12-17.

Ruby

One of the most important gemstones ruby. Inclusions may be solid, liquid, r gaseous. Coarse stubby crystals, hich may be zircon, garnet, rutile, oinel, mica, or corundum, are found. egative crystals and liquid-filled "fin- erprints" are common. Perhaps the ost characteristic inclusions are long, iin rutile needles, sometimes in patches, ıt almost always oriented in three roups which follow the crystal structure ıd cross each other at angles of 60 ıd 120 degrees. Figs. 12-2 and 12-3. oarser needles are found in Siam ıbies; much finer ones, often called silk," in Ceylon stones.

Zircon inclusions, surrounded by ir- gular, dark, pointed areas, are con- dered typical of Ceylon stones. These ark areas are caused by the action of e radioactive zircon crystals on the urrounding crystal structure. These dioactive areas surrounding zircon ystal inclusions are called "halos." am rubies are more likely to contain ystals and liquid inclusions, including ingerprints." Seldom, indeed, are ru- es from any source completely flawless.

Sapphire

Sapphire, a very valuable stone when the finest color, is of interest to the erage amateur gem cutter because it available in the rough in many in- eresting colors that are inexpensive. general, inclusions in sapphire follow ose of the ruby from the same district. pphire from Burma, Siam, and Cey- n may be expected to contain approxi- ately the same types of inclusions as bies from the same districts.

Fig. 12-17. QUARTZ. 10X. Seen in polarized light, this twinned appearance in quartz is a shifting of crystal layers rather than twinning.

Cashmere sapphires, which include those of the now very rare and valuable cornflower blue, often have a somewhat hazy appearance, called "sleepy" in the trade. The haze seems caused by numerous, oriented, hazy lines of uncertain makeup. Also many very fine liquid-filled inclusions in various patterns can be found.

Inclusions in Montana sapphire seem to follow those of sapphires from Siam in appearance. Perhaps the surface color and appearance of Montana sapphire is its most important characteristic; a steely blue with a slight metallic cast is most common.

Stars in sapphire, as in ruby, are caused by a concentration of oriented "silk" or fine needles.

Of the inclusions found in corundum, the most distinctive is the oriented needles or "silk." Common to both ruby and sapphire from certain districts, it is quite distinctive to the experienced gemologist and to others who understand the slight difference between the orientation of the needles in corundum and in certain species of the garnet.

To understand the orientation of needles in corundum, consider the sapphire. Its crystal habit is an elongated bipyramid, hexagonal in cross section. The needles lie in three groups each of which is parallel to two opposite sides of the hexagon and *at right angles to the*

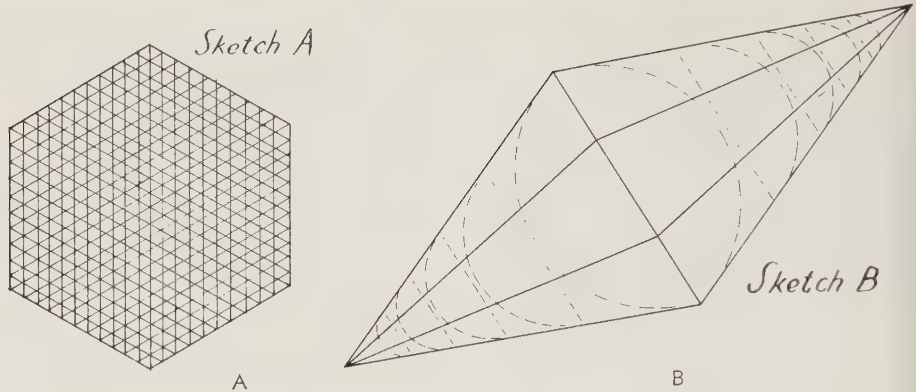


Fig. 12-18

long axis of the crystal. Needles always follow the hexagonal crystal structure. They never run lengthwise of the crystal. See Fig. 12-18, A.

If the crystal contains a sufficient concentration of needles to cause a star, stones can be cut with their backs at right angles to the long axis of the crystal, perhaps as shown in Fig. 12-18, B. If the crystal is large enough, several cabochons can be cut from each section and each stone will have a correctly oriented star.

The needles are in three groups, each group at 60 degrees from the next, and *in one plane* which is perpendicular to the length or C axis of the crystal.

Star Garnet

In superficial appearance, the characteristic inclusions in the almandite-rhodolite-pyrope group of the garnet species are very much the same as the oriented rutile needles in corundum. Upon closer examination several differences will be noted.

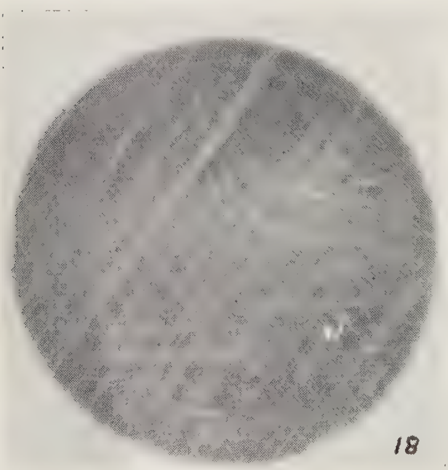


Fig. 12-19. ALMANDITE. 30X. Hornblende needles oriented at 70 and 110 degrees in more than one plane. Occur also in rhodolite and pyrope.

Dr. Gubelin believes the black, needle-like inclusions in garnet to be rods of hornblende. Fig. 12-19. Never as fine or "silky" as the finer inclusions in corundum, they are also oriented differently. In corundum the needles are oriented at 60 and 120 degrees in one plane. In garnet the needles are at 70 and 110 degrees in one plane with other groups at 70 degrees from that plane. They are oriented in directions that parallel the edges of the rhombic faces of the rhombic dodecahedron.

While it may be difficult to differentiate between the 60 and 70 degree angular relation, the easily noted difference is that corundum needles, however viewed, will be seen to lie all in one plane. Garnet needles will be seen to lie in two or more planes, more nearly approaching a "haystack" appearance. The needles in corundum always seem quite symmetrical in contrast.

Emerald

Inclusions in emerald are of many kinds but the really distinctive ones are the three-phase inclusions seen in emeralds from Colombia and the Ural Mountains of Russia. The term three phase is descriptive of inclusions that consist of all three phases of matter — solid, liquid and gas. These most interesting inclusions consist of flat, irregularly shaped voids, liquid-filled. Suspended in the liquid is a solid crystal and a gas bubble. Fig. 12-6.

Three-phase inclusions are rather small and of very low relief. Only an expert would be likely to find them with a loupe. In fact, it is quite difficult for the average person to see and define them the first time. Knowing what to look for, they are easily seen with a Gemolite type, binocular microscope and magnification of 30X to 75X.

These inclusions are not found in emerald from India or Brazil. They are not found in synthetic emeralds although the maker, Carroll Chatham, has said he could produce emerald with three-phase inclusions if he so desired.

A peculiarity of three-phase inclusions is that the shape of the included crystal is considered evidence of the geographical source of the emerald. The ncluded crystals in emerald from Coombia are square, tabular-shaped halite (salt). Those from Russia are diamond or lozenge-shaped, mineralogical identity unknown. Most emeralds, whatever their source, have two-phase inclusions liquid and gas). Two-phase inclusions are common to synthetic emeralds, also.

Slight, but noticeable, difference of color will distinguish between emeralds from the two prime mine sources in Coombia. Emeralds from the Muzo mine are a slightly yellowish green. Those from Chivor are bluish green.

Muzo emeralds often have, as inclusions, fragments and crystals of calcite. Minute crystals and groups of pyrite are frequent inclusions in emeralds from Chivor.

Brazilian emeralds, often free of inlusions, are much lighter in color than hose from Colombia. Usual inclusions re *feathers* formed from healed fracures, and flat, liquid-filled voids of irregular outline. They have no three-phase inclusions.

Inclusions in Russian emeralds, other han three-phase, usually consist of liquid feathers, small mica flakes, and acinolite rods.

Indian emeralds, a comparatively reent discovery, have inclusions similar o those from Russia, except that no hree-phase inclusions are present. Mica akes, rods of actinolite, and liquid-lled, flat maplike areas are among the nclusions found. Some two-phase inclusions are seen.

Emeralds from Transvaal, South Africa, have only one distinct type of inclusion, visible under low magnification. These are feathery cracks from a central point, non-oriented. Of high relief, dark to almost black, once seen, they will be easily recognized thereafter.

Topaz

In general, topaz contains fewer inclusions than most of the more common gem stones. Liquid inclusions, drop-shaped, and two-phase inclusions are common. Fig. 12-5. Irregular and drop-shaped voids containing two non-miscible liquids are common in topaz. The two liquids are considered to be liquid carbon dioxide and water.

Spinel

Inclusions in spinel are not widely varied. Most distinctive are groups or planes of tiny, dark octahedra. They are not always sharply defined as to octahedral outline, but in each group some will appear clearly octahedral. They sometimes follow a plane or curvature as if formed during the healing of a fracture.

Spinels from Ceylon may contain radioactive zircon inclusions with the halos seemingly typical of that area.

Zircon

Zircons have no distinctive inclusions. Strong doubling of the back facets is an excellent indication of identity (Fig. 12-20a) when coupled with over-the-

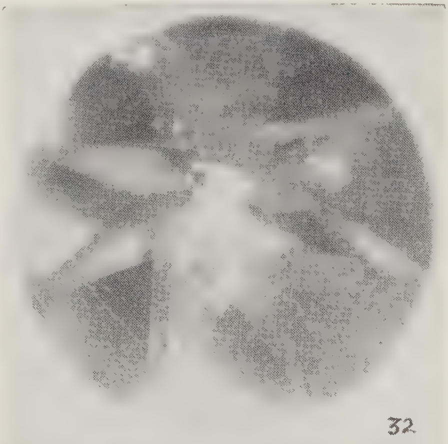


Fig. 12-20a. ZIRCON. 30X. Notable doubling of image seen through any strongly doubly refractive gem.

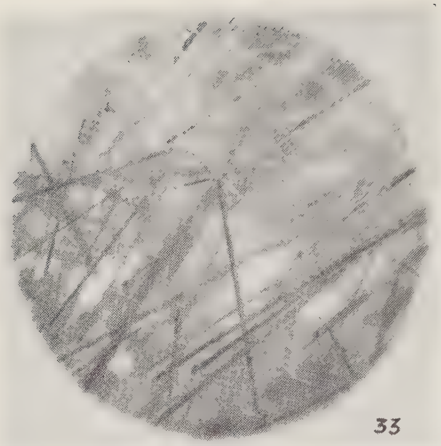


Fig. 12-20b. ZIRCON. 30X. Nonoriented tubular inclusions, liquid and clay-filled.

Fig. 12-20c. ZIRCON. 30X. Growth lines and large bamboolike tubular inclusion.

scale R.I. (over 1.80). Figure 12-20b shows non-oriented, tubular inclusions in zircon. Figure 12-20c is a single, large, bamboo-like tube. Such inclusions are found in other minerals, also.

Quartz

Crystalline quartz is often quite free of inclusions. Considering the wide number of quartz varieties, there are few distinctive inclusions.

Perhaps the most common inclusions are negative crystals. Common to amethyst, rock crystal, smoky, and morion varieties, usually liquid-filled, and rigidly oriented, these inclusions do have some degree of distinctiveness. Fig. 12-10. Patches of irregular liquid-filled inclusions are common, but are not distinctive because they are also common to many other minerals.

Thin, rutile needles, often called "Venus' hair," in straight or curved masses, are common in quartz. The name *sagenite* is defined by Fay as quartz containing acicular crystals of rutile (called Venus' hairstone), or similar crystals of tourmaline, hornblende, goethite, or stibnite. Rock crystal containing acicular crystals of actinolite is called "Thetis' hairstone."

Also in rock crystal, as inclusions, may be found larger rods of tourmaline or actinolite, hematite roses, magnetite in the form of octahedra, or chlorite masses. Fig. 12-21. When several of these combine to form fairylike flower gardens in quartz something unique and beautiful results. See Fig. 12-8.

A growth peculiarity of some quartz should be mentioned. Sometimes a striated appearance will be seen on a fracture surface of citrine or amethyst. Or, when a stone is examined in polarized light, the appearance of a laminated structure or repeated twinning will be seen. Fig 12-17. The laminae run parallel to the C axis. Dr. Gubelin speaks of this effect as "dry cracks" and says it is often found in amethyst and heat-treated citrine, possibly caused by a shifting of crystal layers.

Of inclusions in chalcedony or cryptocrystalline quartz, little need be said. Dendritic agate, with many treelike inclusions of manganese oxide, is becoming quite fashionable. The old name for this material was mocha stone. It is now being popularized by the jewelry trade as "tree agate."

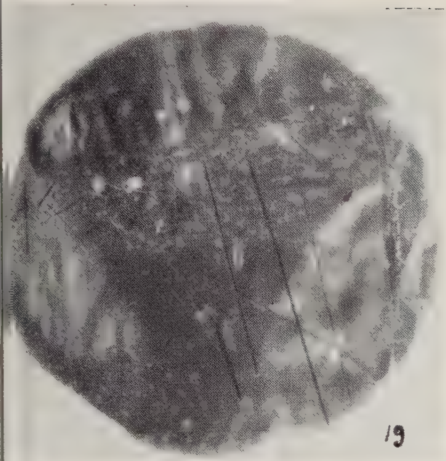
Occasionally seen are white, fossilized, marine shell fragments in black chalcedony. It is very distinctive in appearance. Fig. 12-21a.

Inclusions in dendritic opal, very similar to those appearing in agate, are also caused by manganese oxide.

Moss agate shows many and variously shaped, highly colored inclusions of almost every imaginable form. Such material is quite distinctive in over-all appearance and needs little identification.

The Garnets

Almandite, rhodolite, and pyrope; do not try to distinguish these garnet species by their different inclusions. Any or all of them may have the dis-



g. 12-21. ROCK CRYSTAL. 10X. Tour-
aline needles.

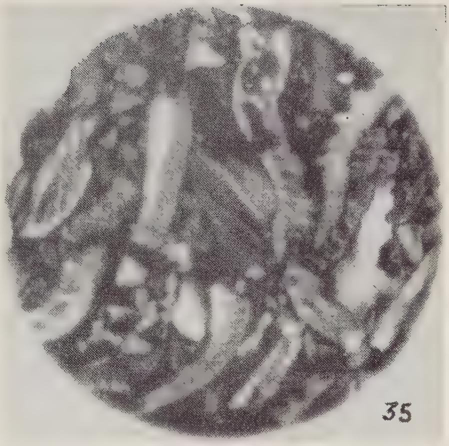


Fig. 12-21a. FOSSIL AGATE. 10X. Fossilized white fragments of marine shells included in black agate.

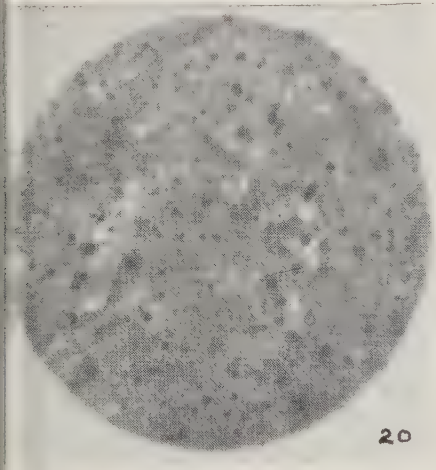
ctively oriented, needlelike inclusions
hich were described in a paragraph
llowing our discussion of the oriented
ilk" in sapphire. Fig. 12-19. Separa-
on of these species should be on the
ases of their color and refractive index.
formation about this will be given
ter.

In addition to the oriented needles
ten found in almandite, rhodolite and
rope, numerous small euhedral crys-
ls may be seen. Sometimes of low re-
f, as are those in hessonite, sometimes
higher relief, they are quite easily
en with a loupe. Fig. 12-22. Between
d around these crystals the dark, high
lief needles may be seen. Occasionally
dioactive zircons, complete with halo, may be found in garnet from Ceylon.

Demantoid Garnet

Demantoid, the fine green andradite garnet, the most valuable of the garnets found in jewelry trade channels, has what is probably the most distinctive and easily recognized of all inclusions in gem stones. Fig. 12-1.

Horsetail inclusions, the very descriptive term for these inclusions, are considered positive proof of the gem's identity. Actually, they are a threadlike form of asbestos called byssolite and one may confidently expect to find them to an identifiable extent in all demantoid, except possibly an occasional, very small stone. They are a beautiful inclusion of off-white to tan color, diverging from



. 12-22. ALMANDITE. 30X. Low relief
pside, and darker zircon inclusions.

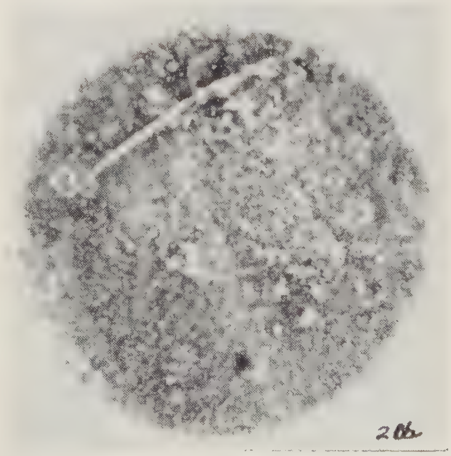


Fig. 12-22a. ALMANDITE garnet with many small crystal inclusions. 30X.

a common source, looking much like a horse's tail that had been lowered in water until the hairs became somewhat separated, raised, then quick-frozen in the crystal structure of the demantoid.

Medium and large gems of demantoid will usually enclose a full horsetail or a major part. Small and very small stones may show only a short section of a single fiber but it still has its distinctive appearance. They occasionally occur in a disorderly tangle which resembles the activities of a kitten with a skein of thread. This type is uncommon. Horsetail inclusions in medium to large stones are usually of a size to be barely, but clearly, visible to the eye without magnification.

Hessonite Garnet

Hessonite, an orangy variety of grossularite garnet, is particularly known for its many included stubby crystals of low relief. Fig. 12-7. They are probably crystals of diopside, many of which appear well rounded. Sometimes they are so numerous as to fill the stone. Much less plentiful are the occasional crystals of much darker zircon of noticeably higher relief.

The British gemmologist, Herbert Smith, in his book, "Gemstones," mentions hessonite as having a granular appearance under the microscope "as if it was made up of imperfectly fused grains." Under low magnification it has been noted that a fractured surface on hessonite from Ceylon sometimes has the appearance of an irregularly broken series of hexagons. However, a decided "heat wave" effect, much like that seen over a paved road on a hot day, will be noted in most hessonite. Some books mention it as an oily appearance.

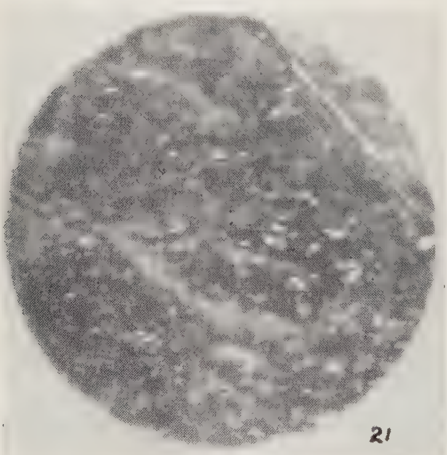


Fig. 12-23. SPESSARTITE. 75X. Minute, liquid-filled feathers found in spessartite only.

Spessartite is a garnet species not often encountered in the jewelry trade, and then usually by accident. A lapidary friend once came to my lab, saying, "How about identifying this hessonite for me?" He had five yellow-orange, neatly faceted stones, from three-quarters to one-and-a-half carats. He said he had bought the rough from a miner who had just found a pocket with several hundred such crystals. He had paid $6.00 for nine crystals of the "hessonite!"

I rotated one stone in the polariscope —singly refractive. I placed it on the refractometer, confidently expecting a reading of about 1.74. Not so. The R.I. was 1.79. It had to be spessartite!

Under the microscope, a few of the typical, liquid, feather groupings were visible. These inclusions look like wavy feathers, sometimes in tuftlike groups, but disseminated through the stone like feathers tossed from a broken pillow and frozen in position while slowly settling. Fig. 12-23. No other garnet, probably no other stone, has these oddly distributed liquid inclusions.

Tourmaline

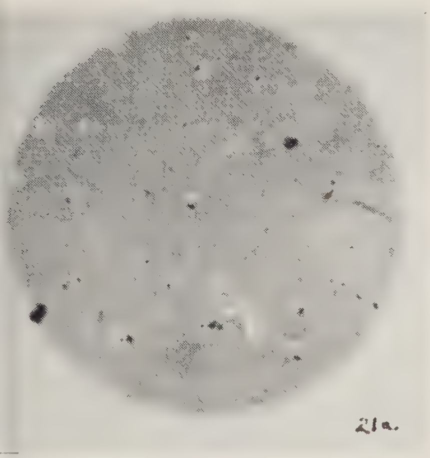
The nearest to a distinctive inclusion in tourmaline is a series of threadlike capillary tubes. They may branch and have a rather shrublike form. They occur in stones of any color, from any locality. It is doubted that the capillaries are the same as the oriented tubes which are the cause of the fine cat's-eye in some tourmaline.

Peridot

Peridot is quite free of inclusions in most cases. No distinctive inclusions occur in peridot from Arizona.

Peridot from the Island of Zebirget (St. John's Island in the Red Sea), often shows inclusions of brown biotite mica of hexagonal outline. These are quite distinctive, apparently occurring i peridot from no other locality.

Hawaiite, the variety name given t light green peridot from the lavas o



g. 12-24. HAWAIITE, a variety of peridot, ith bubblelike inclusions. Each bubble has black center.

e Island of Hawaii, has unique inclu-ons. It is often taken for a green vol-nic glass because of the bubblelike ppearance of the inclusions. Light in lor, almost spherical, random place-ent gives them a close resemblance to e gas bubbles in glass. Fig. 12-24.

In Hawaii, these stones are often lled "Pele's Tears." Pele (pronounced y-lay) is the goddess of Hawaiian vol-nos, believed in by 90 per cent of the lands' population.

Aquamarine

Gem stones of aquamarine are remark-ly free of inclusions. Tubular inclu-ons, hollow or partially liquid-filled e seen in some stones. Mention is made by Dr. Gubelin and the Gemological Institute of America of another inclusion, typical of aqua, called *snowflakes.* These are flat, consisting of a crystalline center surrounded by many radiating, liquid-filled drops.

Moonstone

The adularescent variety of orthoclase feldspar has one very distinctive type of inclusion. Fig. 12-25. These odd inclusions have been likened to a centipede. The name is fairly descriptive but they could also be said to resemble one or more railroad tracks, with the outer tips of the ties bent forward and backward at about 45 degrees. What could be more distinctive? These are not present in all stones but are in at least 50 to 75 per cent of other than small stones. A magnification of 10X to 30X defines them very clearly.

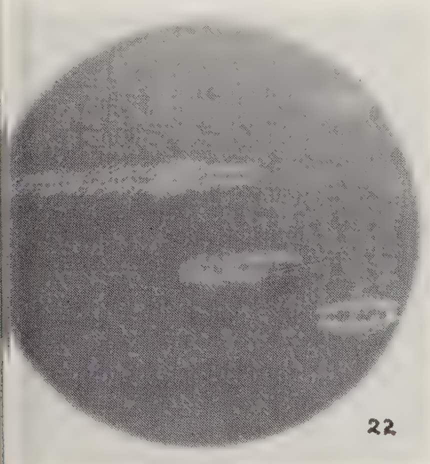
They appear to consist of many non-liquid-filled cracks, oriented with the "tracks" in the direction of the C axis. No other stone is known to have similar inclusions.

Chiastolite

Although opaque, chiastolite, a variety of andalusite, has rather noteworthy inclusions. Caused by crystallographically oriented carbonaceous impurities, a light or dark, contrasting, colored cross is seen in the center of each crystal. Fig. 12-26.

Lapis Lazuli

Lapis lazuli is a fine, blue gem rock composed of approximately 15 minerals.



. 12-25. MOONSTONE. 30X. Centipede lusions, oriented parallel to "C" axis.

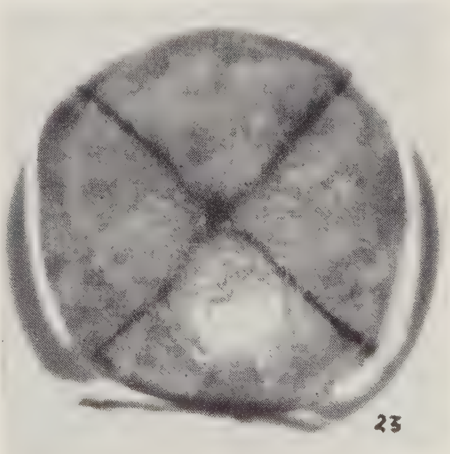


Fig. 12-26. CHIASTOLITE. 10X. Oriented carbonaceous inclusions cause the cross.

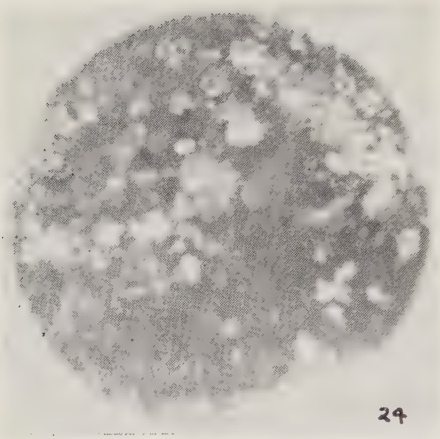


Fig. 12-27. LAPIS LAZULI. 30X. Pyrite inclusions in surface of polished stone.

To aid in its identification Nature has included small grains of pyrite which, after cutting, flash like flecks of gold. Fig. 12-27. Lapis from Chile does not usually include pyrite but is more apt to have an excess of calcite which causes white areas in the blue. Lapis from Persia (Iran) and Afghanistan always seems to have some pyrite.

Diamonds

Of only nominal interest to the amateur, but truly the lifeblood of the jewelry trade, diamond will be mentioned here with reference only to its inclusions. No description of other flaws, blemishes, or imperfection grading will be given.

No really distinctive inclusions seem to be found in diamond, that is, distinct to the person or gemologist of ordinary experience. To the diamond expert, or to anyone with wide experience in handling diamonds, almost all inclusions are distinctive. All inclusions in diamond seem to have a slightly different appearance, difficult to describe.

Many forms of solid inclusions are found. Inclusions of other diamond crystals, differently oriented, are common. Fragments of the original magma, zircon, garnet, magnetite, ilmenite, hematite, and graphite are found. Any dark spots or areas in diamond are called *carbon,* even though they are much more apt to be ilmenite.

Probably the nearest to a characteristic inclusion in diamond are the irregular cracks, combining minute fractures and cleavages, called *feathers. Clouds* are white or dark areas resulting from groupings of minute inclusions. The dark clouds are probably flecks of ilmenite.

Knots are included diamond crystals. If oriented differently from the surrounding crystal, they may add difficulty when cutting the diamond. When sawing diamond, the saw will cut in one crystallographic direction only. When the blade (thin phosphor bronze, about 3½ inches in diameter and .005 inches thick, charged with diamond dust) strikes a knot, it crumples. It is then necessary to cut from the other direction until again striking the knot, after which the crystal is broken the remaining distance. Occasionally a knot may protrude slightly from a facet after completion of cutting and polishing.

A *natural* is some part of the original diamond crystal surface remaining visible on the girdle or culet after cutting and polishing. It is considered an imperfection but not an inclusion.

Amber

Amber is a fossil resin, an organic gem material, not a gem mineral. Its color gives it much beauty, its insect inclusions give it much interest. Amber is the solidified and fossilized sap from an extinct pine tree, the *pinus succinatus.* The highly fluid pitch attracted insects which became enshrouded and later fossilized for the amazement and amusement of modern man. Fig. 12-28.

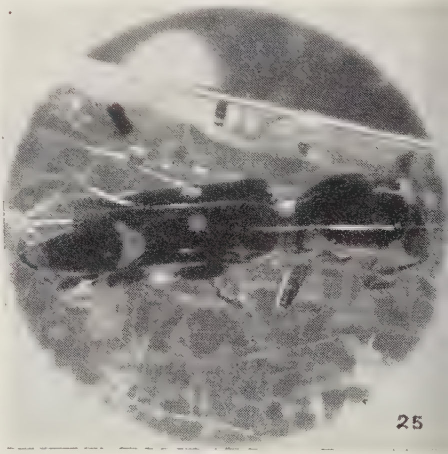


Fig. 12-28. AMBER. 10X. Wood borin beetle inclusion. Many other insects, eve snails, have been found.

Insects in amber include a wide vaiety of species. Flies, mosquitoes, gnats, eetles, and even frogs and snails have een found in amber. Many of these inects are now extinct since amber was ormed from one to ten million years go.

Amber with insect inclusions brings igher prices so, of course, there is some aking. The most common method is to often the clear amber chemically and mbed hard insects, such as beetles, beeath the surface. This can sometimes e detected with a microscope as the oftening and rehardening usually gives ne amber surrounding the insect an inistinct, wavy appearance. Amber which as been exposed to air for many years ill show many surface checks.

Modern plastics of proper color, with mbedded insects, are sometimes used as mitation amber.

Glass

Glass probably has been the most idely used substance for gem stones in ncient or modern times. It has the adantage of being both cheap and good ooking, and of course, the disadvanges of a complete lack of rarity and urability.

In the jewelry trade it is called *paste* r *strass*, and many less polite names by welers, as it is widely used for gem nitations. Very seldom, but occasionly used with intent to deceive, glass an be made to imitate almost any gem one. Such imitations are sometimes early perfect. Color, texture, phenomna, almost anything except hardness nd toughness can be imitated.

As for inclusions in glass, it must be cognized that many glass gems are ompletely free of inclusions or distinuishing swirls. When made to deceive, may have very lifelike inclusions of lmost any type. Bubbles may be so retched as to appear like the tubular clusions of natural gems. They will ways have highly lustrous and smooth des, and rounded or sharp, pointed nds. Be alert for any type of swirl arks which definitely prove an amorhous structure. Fig. 12-14. Gas bubbles e a most probable inclusion.

Moulded glass stones, unless the facets e individually polished, will show some concave facets and rounded facet junctions. The girdle may show some hint of glass edges resulting from the imperfect junction of upper and lower halves of the mould.

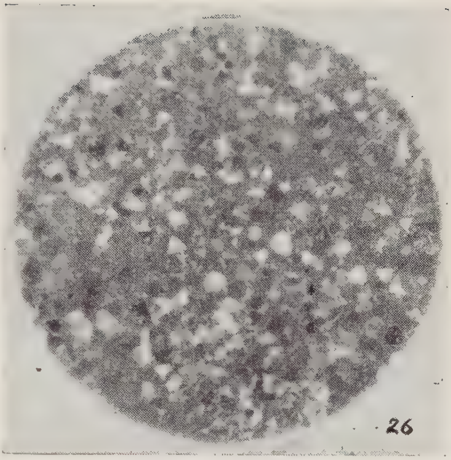


Fig. 12-29. GOLDSTONE. 30X. Fine copper crystals in brown glass. Note numerous triangular and hexagonal copper crystals.

Glass may have almost any type of solid inclusions added while in plastic condition. The addition of such solids usually increases the number of bubbles.

One of the better kinds of glass, not intended as an imitation of any gem, is goldstone. Fig. 12-29. Copper crystals have been added, or precipitated chemically, in a brown or other colored glass which gives a very attractive golden glittering effect. The method of making this glass has been a trade secret for many years. Goldstone was in vogue in the latter part of the 19th century, the "Saratoga Trunk" period. It now seems to be regaining its former popularity. It is for sale in rough form in rock shops and as cut stones in most jewelry stores.

Assembled Stones

Assembled stones are not by any means the easiest gems to identify. Under this term are included doublets, triplets, and foilbacks. A *doublet* is two separate sections of material, fused or cemented together to make a complete stone. The back portion gives color to the stone and the top section, often almandite garnet, is added for hardness.

When two light or poorly colored sections are cemented together with a cen-

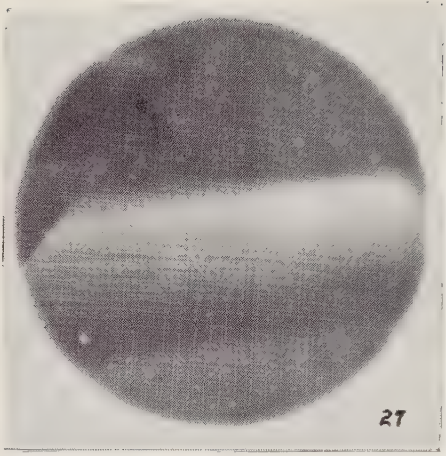


Fig. 12-30. SYN. RUBY. 30X. Curved striae, spherical gas bubbles.

ter section of the color desired. the composite stone is called a *triplet.* If of natural materials, the inclusions in doublets or triplets will be in accordance with the species of the different portions. But almost always, whether the sections are cemented or fused together, air bubbles will be seen on the plane of junction.

The most common doublets are composed of a glass back, fused or cemented to a very thin top layer of red garnet. Under magnification, air bubbles may be seen in the glass back, the junction plane may show numerous bubbles, and a few oriented needles may be seen in the top garnet section. Fig. 12-13.

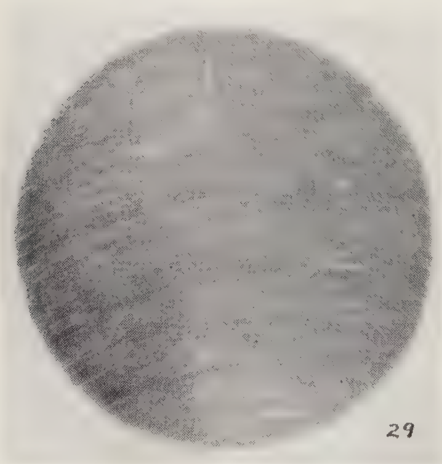


Fig. 12-30b. SYN. RUBY. 30X. Curved striae interspersed with fine gas bubbles. Seen only in stones cut from lower tip of boule.

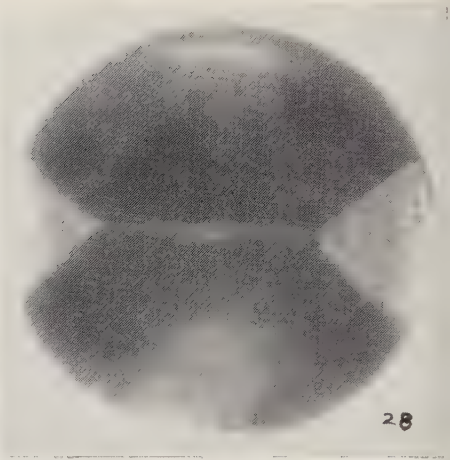


Fig. 12-30a. SYN. RUBY. 30X. Note indistinct curved striae visible in each light section, curvature very slight.

The center colored section in triplets, commonly a colored plastic cement, is often fluorescent. Such stones examined under ultraviolet light offer easily evident proof of an assembled stone.

In those instances when there are no bubbles at the junction plane, the stone should be immersed in a fluid of high R.I., such as bromoform or methylene iodide, and observed under magnification, and the parts of the composite stone will be apparent.

Included under assembled stones are the *foil backs.* The foil backing should be visible under any inspection and the inclusions will be according to the stone's composition.

Synthetic Stones

Inclusions in synthetic stones are in accordance with the method of manufacture. Synthetic ruby, sapphire, spinel, rutile (Titania), and strontium titanate (Fabulite) are made by slightly varying processes involving crystallization following a reduction in temperature from a molten state.

Synthetic or cultured emerald is assumed to be made by slow crystallization from a solution. This is known as the hydrothermal process. A synthetic or cultured ruby is also made by this process.

Distinctive inclusions in synthetic ruby made by the furnace process, that is distinctive proof of its synthetic origin, is in two forms, spherical gas bubbles and curved striae. Figs. 12-12, 12-30, 12-30a, 12-30b. Spherical gas bubbles may be of any size from that requiring at least 75X to distinguish, to the size of the head of a wooden match. They may be widely dispersed through the stone or in compact groups or clouds. If the stone has been identified as ruby, one bubble is sufficient proof of its synthetic origin.

Curved striae is another name for the growth lines of the boule in which ruby was grown. Much more tenuous, more difficult for the beginner to find than gas bubbles, curved striae are excellent proof of synthetic origin. Even when the radius of the curvature is large and the narrow shadows appear straight, the striae do not look like the straight or angular striations of the natural mineral. Compare Fig. 12-12 with Figs. 12-2 and 12-31.

When stones are cut near the beginning or tip of the boule the curvature of the striae is very great and possibly more noticeable because of the presence of many fine bubbles. Fig. 12-30b. The curved lines, which are only visible from a direction at right angles to the long axis of the boule, are only a series of slightly curved shadows, medium and darker in color. In about 90 per cent of medium and large cut stones the striae will be visible only at some angle through the table.

Most corundum boules are split lengthwise, after manufacture, to relieve internal strain. This makes it more practical to set the table of a stone to run parallel to the long axis. This direction is not an ideal direction to obtain the best color. When possible, natural stones are cut with the table perpendicular to the major axis. This difference in orientation of cutting is an *indication*, but not a proof, of the stone's origin.

Another indication, perhaps slightly better than the one above, is the presence of rapid polish cracks or checks near the facet junctions of the stone. Fig. 12-11. Found on most synthetic rubies of oriental cut, these checks result from fast heating and cooling of the facet surface during the polishing operation. Natural rubies, being of much greater value, are not subjected to this fast polishing routine. This condition is an indication only, not a proof.

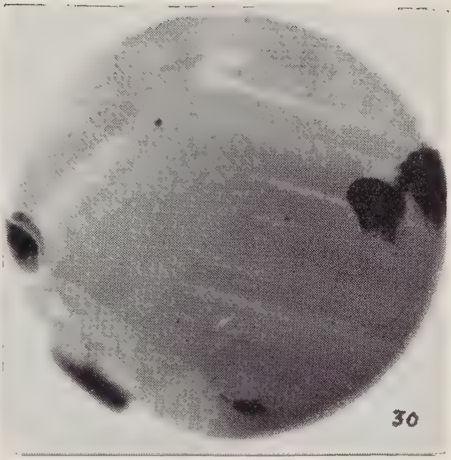


Fig. 12-31. SAPPHIRE. 30X. Angular striations intersecting at 120 degrees. Proof of natural origin. Dark spots are clay inclusions.

Almost all rubies are fluorescent but generally the synthetics are more strongly so. It is said that large importers of natural stones often make a preliminary check for synthetic stones by spreading the parcel and exposing it to ultraviolet light. Stones of noticeably high fluorescence are then more carefully checked by other means.

Reconstructed ruby was the term applied to stones made by fusing uncuttable fragments of natural ruby. The process went out of use about 1900 when synthetic rubies were marketed. Stones made by the process have completely disappeared from the jewelry marts now and are very rare. The name still persists, used by many of the old-time jewelers for synthetic ruby. True reconstructed rubies are detectable under magnification and polarized light. They contain intersecting curved striae with a swirl-like effect and differently oriented doubly refractive areas. Gas bubbles are plentiful.

In general, our remarks about inclusions in synthetic ruby apply equally to the darker colors of synthetic sapphire. Gas bubbles are equally apt to be present, but easily visible curved striae are less common. It is usually possible to define some curved striae in the darker colors of sapphire, but seldom or never in the light colors and colorless.

Strong fluorescence is not universal in synthetic sapphire. Some colors fluoresce only under a strong ultraviolet light.

A last note about synthetic corundum. Dr. Gubelin reports that in some cases, a careful microscopic search in calculated crystallographic directions may reveal oriented striations similar to those in natural stones. Unlikely to be found except under research conditions, this fact should be known, "just in case."

Synthetic star corundum inclusions are similar to those in non-asteriated stones with the difference that star stones, because of the inclusions necessary to form the star, are never completely transparent. To find bubbles or curved striae, stronger light must be used. When it is impossible to see into the stone, the very perfection of the star, and with a little experience, the even distribution of the very fine rutile needles which cause the star, offer sufficient proof of synthetic origin.

The above remarks about synthetic stars apply particularly to those of Linde manufacture. In the older Linde stars, the rutile needles were very shallowly grown near the surface of the stone. Those of modern manufacture have needles throughout the stone.

Another type of star stones is made from clear, transparent corundum by scoring the back or applying a ruled mirrorlike backing. This type is more easily examined internally. The G.I.A. terms these stones *synthetic foil back stars.*

Fig. 12-32. SYN. SPINEL. 10X. Patchy extinction or anomalous double refraction observed in polarized light in all synthetic spinel. Caused by internal strain.

Synthetic spinel inclusions are principally gas bubbles. There are no curved striae. Somewhat fewer gas bubbles are found in spinel than in corundum. Bubbles are often single or very small, widely dispersed groups. Stones may have a single bubble, or none.

Occasionally, bubbles in spinel may assume distended or "whorled" shapes. Spinel has a strong tendency to crystallize in cubic crystal forms. Even though rapidly cooled, boules usually assume a shape that is a round-cornered square in cross section. This tendency toward crystallization affects even the larger bubbles, resulting in odd shapes. Whorled bubbles may even find opportunity to orient themselves crystallographically in the boule.

Synthetic spinel boules may always be expected to have a definite amount of internal strain. When cut stones are examined in the polariscope, anomalous double refraction in the form called *patchy extinction* will be seen. Fig. 12-32. This effect is always present to some extent and is considered proof of spinel's synthetic origin. Anomalous double refraction is never seen in natural spinel unless quite large inclusions are present. In this case the inclusions themselves will prove natural origin.

Synthetic rutile (trade name, Titania) needs nothing in the way of distinctive inclusions for its identification. However, synthetic rutile in most cases does have some included gas bubbles. They are less numerous than in corundum, but if present, they are easily seen under 30X magnification.

More distinctive than gas bubbles is the strong doubling on opposite facets when observed through the stone under magnification. This is due to the high birefringence of this material. Note the doubling of back facets in zircon as seen in Fig. 12-20a. Birefringence of synthetic rutile is much greater and separation of the lines seen through the stone will be much wider. To observe this doubling effect, the stone must be oberved in a direction that is doubly re- ractive. Most professionally cut syn- hetic rutile is oriented for cutting with he table perpendicular to the long di- ension of the boule. This makes the rea seen through the table singly re- ractive. Turn the stone slightly and bserve through one of the crown main acets. Doubling will be quite evident.

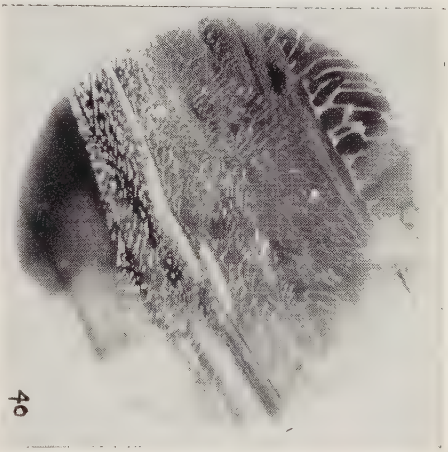
The latest addition to the synthetic st is strontium titanate. At first called tarilian, the current trade name is Fab- lite. As there is no natural equivalent, is not a true synthetic. But it is a ery fine gem material.

As yet we have been unable to acquire specimen for testing. From hearsay, e believe the usual nominal number of as bubbles will be found. Like syn- etic rutile, there are no curved striae. crystallizes in the cubic system, is ngly refractive and has no doubling f the back facets. Identification and paration from diamond and synthetic tile will rest on specific gravity and her factors.

Synthetic Emerald

Synthetic (sometimes called "cul- red") emeralds are grown from a solu- on by a secret process, supposedly very ose to Nature's process. The inclusions esemble those of Nature, including two- hase and liquid inclusions. The maker, arroll F. Chatham of San Francisco, as said it would be possible to grow eralds with three-phase inclusions if so desired.

Many rather tenuous inclusions, vari- sly described as wisplike or veil-like e included. Two-phase (liquid and as) inclusions are common as are ir- gular areas of liquid-filled inclusions. ome small euhedral crystals of phena- te are seen. Identity of synthetic em- alds should not depend wholly upon clusions. Synthetic emeralds are some- hat lower in R.I. and S.G. than stones om Colombia and Russia, and show eater fluorescence under U.V. light. In rong light under a Chelsea filter a ronger red color may be seen. No one test should be considered as proof of synthetic origin. Mr. Chatham is now manufacturing a synthetic (or cultured) ruby, also.



Figs. 12-33 and 12-34. "Fingerprint" inclusions in Ceylon sapphire. 30x. These inclusions are called "feathers" in England. The stones used for photography were loaned by Kenneth Parkinson, gem dealer of Hull, England.

Reference—
The finest book on inclusions in gem stones is: **Inclusions as a Means of Gemstone Identification,** by Edward J. Gubelin. Published by the Gemological Institute of America, 11940 San Vicente Blvd., Los Angeles 49, Calif.

Chapter 13

Synthetic Gem Stones

Far too many persons confuse synthetic with imitation gem stones. They feel that synthetic is only a new name for artificially made imitations of real gems. This is far from the truth.

The word *synthetic* is an honorable one. Synthetics are *real gems*, but are real gems *made by man* instead of by nature. To be classed as a true synthetic, a gem must have the same chemical composition, the same crystallographic character, and the same physical and optical properties as a natural mineral. But regardless of how real they are, they are not minerals, because a mineral must be made by nature, unaided by man.

Something that few people seem to understand is the requirement of a true synthetic, that it be *a man-made version of a mineral made by nature.* We will refer to this requirement in a later paragraph.

Man's laboratories have synthesized over a hundred minerals but only four are being made commercially as gem materials: corundum (ruby and sapphire), spinel, emerald, and rutile. Quartz is being made for scientific purposes but not for gem use.

Notice that the list does not include strontium titanate, called Fabulite by the makers. Fabulite cannot be classed as a true synthetic since it has no natural counterpart among minerals. It is a man-made gem material and a very fine one.

Synthetics are almost exact counterparts of natural mineral species. They are definitely not imitations like glass or plastic gems.

When synthetic gems were first marketed the jewelry trade seriously expected a severe drop in the value of natural stones of the same varieties such as ruby and sapphire. This did not prove correct. Both natural ruby and sapphire are now much higher in value and in greater demand, and not entirely because of the general uptrend of commodity prices. Part of this increase is undoubtedly because of increased scarcity of fine gem material; part is the result of increased interest in natural gems by those who have worn synthetics.

The wearing of synthetics might be compared with the lady who wears and appreciates a dress that is a copy of a Paris original. Although the dress may be of the same cloth, it is still a copy. We cannot all afford a $15,000.00 ruby or a $1,500.00 original Paris gown.

Synthetic gem materials are made by the following processes:

1. Solidification and crystallization of a liquid following a reduction of temperature, just as ice is formed by freezing. Most synthetics are made by this process, including corundum, spinel, and rutile.

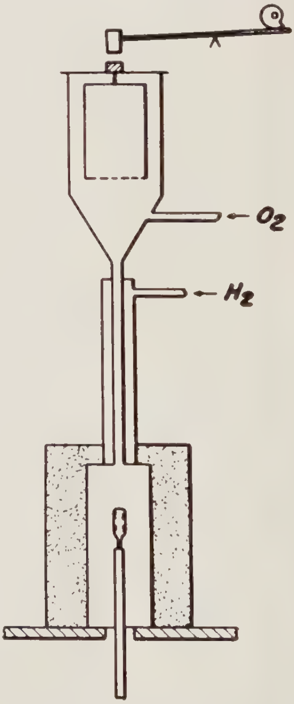


Fig. 13-1. Schematic diagram of Verneuil furnace.

2. Crystallization from a saturate solution. Emerald, ruby, and quartz are made in this way.
3. Direct change from one solid state to another by high pressure and temperature. Diamonds result from this process.

Until 1942 practically all synthetics ere made in Switzerland, with smaller lants in France and Germany. The ecessities of war caused Linde Air roducts Corporation to start research nd production in this country in that ear. Since that time they have pro-uced satisfactory quantities of corunum and spinel and have developed and roduced synthetic rutile and the fine inde star rubies and sapphires.

The methods of making corundum, inel, rutile and strontium titanate are ssentially the same. They are made in e Verneuil furnace or oven (English ronunciation: ver-NEEL). See Fig. 3-1. The very pure, finely pulverized mponents are sifted in at the top of e furnace into which is built an oxydrogen torch.

The boule is started from a small seed ystal to give proper orientation to the ystalline material, on a fire-clay base. e base is rotated and lowered slowly the boule builds up into a rather high, ar-shaped or carrot-shaped mass with e small end down. See Fig. 13-2.

The finely divided powder is conned in the salt-shakerlike container at e top of the furnace. The container is pported by a rod that is tapped regarly by a magnetic hammer. This ves a continuous, controlled sifting of powder down through the flame of furnace.

The Verneuil process was announced 1904 and remains essentially unanged to this day.

Ruby, the best known of synthetic ms, was made experimentally in the t years of the 19th century. It apared on the market commercially in 02.

For several years prior to that time, aps and uncuttable small pieces of tural ruby were fused together by a s flame. The material from this proc- was cut and sold, first as natural by, later as *reconstructed ruby*. Such stones dropped off the market completely following the advent of the true synthetic. They are very rare today. The same name was used for the early synthetics, too, and a few of the older jewelers still use the name for all synthetic ruby. Reconstructed sapphire was never made because of the loss of color during heating.

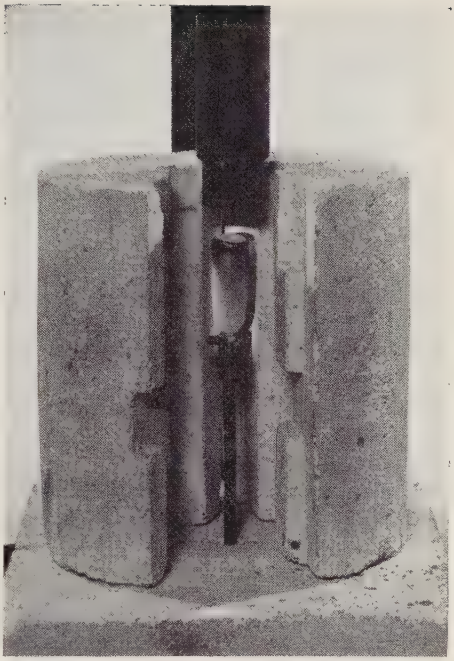


Fig. 13-2. This is how the boule builds up in the base of the furnace.

The composition of ruby is aluminum trioxide ($Al_2 O_3$), commonly spoken of as alumina. Coloring matter is chromium oxide, about one to two per cent. Without the chrome it would not be ruby but colorless sapphire.

The average size of the completed boule is about 225 carats. The cooling of the boule causes internal strain which, if not relieved, may cause it to shatter. This strain is relieved and the boule is split by tapping the small tip with a light hammer. This causes it to divide rather evenly, lengthwise. See Fig. 13-3. No strain remains after this is done. The manufacturers are able to relieve the strain by a special heat treating process, also, after which splitting the boule is unnecessary. This makes possible the cutting of larger stones, differently oriented, and with a finer color. This is

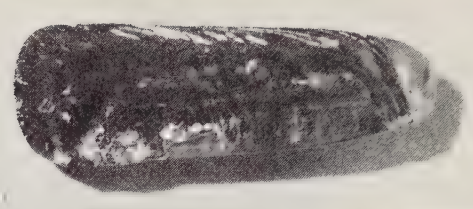


Fig. 13-3. A boule split to relieve the strain. Most boules on the market come this way. Strain-relieved, full boules are also available, usually at a higher price.

not done to the corundum ordinarily on the market.

Most synthetic corundum is sold at retail in half-boules. In this form it is usually advantageous to cut other than small stones with the table set parallel to the long dimension of the boule.

Dichrosim is strong in ruby. The dichroic colors are orangy-red and purplish-red. In this respect synthetic ruby is the same as natural. The most desirable color for ruby is the purplish-red, seen when looking down the C-axis of a crystal or the long dimension of a boule. If a stone is cut with its table parallel to the flat side of a split boule, the color seen through the table will be orangy-red. As very few natural rubies are oriented for cutting in this manner, if the orangy-red color is noticed through the table, it is an *indication* but, of course, not a proof of its synthetic origin.

The color of synthetic ruby, even when properly oriented, is never quite that of a fine natural stone.

The hardness of ruby on Mohs' scale is 9. On a Knoop Indenter scale, it is 1400 to 1450 for natural, and 1650 to 2000 for synthetic stones, giving the synthetic a somewhat higher degree of hardness than the natural.

Refractive index and specific gravity of synthetic ruby are identical to the natural.

The identification of ruby as synthetic or natural rests largely on its inclusions. These were explained in detail in Chapter 12.

Synthetic sapphire was first marketed in 1909, almost ten years after ruby. Considerable difficulty was experienced in finding the proper coloring material. Many oxides were tried and it was found that a combination of iron and titanium was necessary to give a true sapphire blue color. A deeper blue requires some cobalt. A pink color can be obtained by using chromic oxide, the same as ruby, but a smaller percentage.

One of the common synthetic corundums is the imitation of alexandrite, a variety of chrysoberyl. Natural alexandrite has a color change from apple green in daylight to cherry red under incandescent light. A similar color change in synthetic sapphire is caused by the addition of about 3 per cent of vanadium oxide. The synthetic corundum alexandrite shows a rather steely blue in daylight instead of the apple green of the natural alexandrite.

This so called "synthetic alexandrite" is cut in the Orient and has been sold as natural alexandrite to many tourists and servicemen. Strangely, although misrepresented as to species, the cost is usually normal for synthetic stones, seldom over $2.00 per stone.

The proper name for this material is *synthetic alexandritelike corundum*. This is one case where the imitation is harder than the natural stone. Corundum is 9, chrysoberyl is 8½ in hardness.

Aside from the noticeable difference in daylight color, identification of this material can be made from the difference in R.I. and S.G. between the two materials. Chrysoberyl is lower in both properties. If gas bubbles or curved striae are noted in the stone it may be considered synthetic corundum since there is no synthetic alexandrite.

The first synthetic corundum star stones were developed and marketed by Linde in 1947. The stones were excellent, the stars often were better than those of natural origin.

Linde maintained its manufacturing methods as a trade secret for the first few years. After attempts were made to recut the stones it was found that the oriented needles causing the stars were very shallow and if recut, the star was ost. Later, Linde was able to produce tones with needles throughout the body. It then released information to the public about its methods.

The stones are made in the usual boule furnace, the alumina including coloring oxides plus about 1 per cent of titanium dioxide. The boules are clear when formed. After formation and cooling, they are reheated to a temperature between 1100 and 1500 degrees C. This permits the titanium compound to crystallize as fine needles along the prominent crystallographic planes of the corundum. The stones are then ready for cutting into synthetic star stones, ruby or sapphire, according to color.

Spinel

The synthesis of spinel is the result of earlier experiments toward finding a suitable coloring oxide for blue corundum. Many elements were tried. Cobalt was partly satisfactory and when used with a fairly large amount of magnesium, a fine blue color was achieved, but the material was singly refractive and other properties were lower than for corundum. Iron and titanium were found to give a satisfactory color to sapphire, and it was not until 1928 or 1929 that spinel was commercially manufactured.

Corundum (Al_2O_3) with the addition of magnesium becomes spinel ($MgAl_2O_4$). The composition of synthetic spinel is nearer $MgO.Al_2O_3$, but the percentage of magnesium may be as high as 5 times the above or $MgO_5.Al_2O_3$. By strict interpretation of the definition of synthetic, i.e., that it have the *same* chemical composition, this would not be true spinel. But custom allows considerable tolerance and as the properties are those of spinel, it is so accepted.

The colors of most synthetic spinel vary considerably from those of the natural mineral. Blue spinel is found in nature. But others—an intense yellow, intense pink, and a light blue-green, have not been found yet in nature.

Synthetic alexandritelike spinel is seen occasionally. It is reputed to have very natural appearance and a good color change.

Identification of synthetic spinel is usually simple. It is singly refractive and even small stones, if properly viewed in a polariscope, will show a noticeable amount of anomalous double refraction (A. D. R.). See Fig. 12-32. Boules of synthetic spinel cannot be split to remove the internal strain as are those of corundum and the strain is always present. In the polariscope, a gem will usually show A. D. R. in a gridlike pattern, often termed patchy extinction. Such strain is never present in the natural mineral unless there are large, very noticeable inclusions present, and these alone are sufficient identification of the stone as natural.

S. G. is the same for both synthetic and natural. R. I. is somewhat different: 1.72 for natural but close to 1.73 for synthetic.

Spherical gas bubbles, although not quite as common in synthetic spinel as in synthetic corundum, are an excellent proof of synthetic origin. Bubbles are more frequently seen as separated individuals than as large clouds or groups, as seen in most corundum.

Curved striae are never seen in synthetic spinel of commercially produced colors. A few instances of medium red spinel from experimental boules have shown very pronounced curved striae. Such stones may never find their way into jewelry trade marts.

Any completely colorless spinel may be considered synthetic since colorless spinel is not found in nature.

Emeralds

The first synthetic emeralds were produced by I. G. Farben Industries of Bitterfeld, Germany, about 1930. Their process was secret and the stones produced were not of fine color. Their product, called "Igmerald," had scarcely reached the market when research and production ceased because of war.

Our present source of synthetic emerald is from the laboratories of a San Francisco chemist, Carrol F. Chatham. Chatham emeralds appeared on the market in 1935 and from the beginning have been superior in color and quality to the earlier German product. Chatham's methods are still secret but are generally believed to be, as were the earlier German emeralds, a hydrothermal process involving heat and pressure, very much the same as nature's process. The process is a lengthy one; eight to 12 months are required to produce emerald crystals of useful size.

The hardness of Chatham emerald is the same as that of the natural. As to toughness, when asked for an infallible method of separating his emeralds from the natural, Chatham is reputed to have made the following suggestion: "Heat the stone red hot and dunk it in water. It it shatters, it is a natural emerald; if a Chatham synthetic emerald, it will be unhurt." We have not tried it!

R. I. and S. G. of the Chatham emerald are lower than those of the natural stone.

Inclusions are different but considerable experience and a microscope are necessary to differentiate. The natural emerald will usually have some 3-phase inclusions which are not found in the synthetic. See Fig. 12-6. Two-phase inclusions may be found in either. More detail about inclusions was given in Chapter 12.

In color, the synthetic emerald, on the average, appears to be slightly more bluish-green than the natural. When viewed in white light through a Chelsea filter, gems of synthetic emerald appear to have a much more brilliant red color than the natural.

Synthetic emeralds are slightly fluorescent under short-wave ultraviolet light. To see the fluorescence it is usually necessary to place the stone against a black background and hold the light very close; then a dull, brick red color will be seen. Natural emerald, if fluorescent at all, will have much lower intensity.

Most of the above tests do not apply to the small, natural emerald cabochons from Russia, sold by many rock shops for about $3.00 for ten carats. The price alone should separate them from the synthetics which, if of good quality, usually sell for $90.00 to over $100.00 per carat. In the past, synthetic emerald crystals large enough to cut 1 to 2 carat stones have been rare. It is said that improved methods now permit the growth of larger crystals.

In 1959 Chatham introduced his latest product, synthetic ruby. The rubies are said to be of fine gem quality and the largest specimen to date is 40 carats. Both ruby and emerald are termed *cultured* by their manufacturer, since they are produced by a slow hydrothermal process closely approximating that of nature.

Rutile

Synthetic rutile, called *Titania* by the producers, Linde Air Products Corporation, is unique in many ways. It has the highest R.I., birefringence, and dispersion of any present gem material. Linde astonished the world when, in 1948, it marketed the first boules of synthetic rutile. The dispersion was so high as to be almost unbelievable.

The composition is titanium dioxide (TiO_2); hardness about 6½, slightly variable. It is made in Verneuil ovens, much the same as corundum and spinel but with one great difference: when first removed from the furnace Titania is black and opaque.

An additional heat treating process in an oxidizing atmosphere is necessary to clarify the boules. During the latter process they become clear, but are never completely transparent as are diamonds and many other gems. There always seems to be a slight misty or hazy appearance. This is the principal reason why they are not considered as brilliant as diamonds.

The earlier boules were a definite light yellow but by changing the heat treating process they could be made a light but vivid orange, green, blue, or red. The manufacturing processes have been refined and the only boules being marketed at present are very nearly colorless, only a little yellow being noticeable.

When first marketed, Titania was reported to be very brittle. A really expert diamond setter bought a 5-carat stone, one of the first sold. He was thoroughly afraid of it, saying it seemed like trying to set a stone of half-hard butter after setting diamonds for so long. He spent a whole day setting it in a fine white gold mount, probably the most careful job he had ever done. He said he lost ten pounds and it took him three days to recuperate. It would be interesting to know how many he has set since then. Probably many thousands. They are ot really difficult to set.

During the early years of Titania production, a Los Angeles firm developed a method claimed to harden the surface of a cut stone, called "sapphirizing." It was process of deposition of pure, vaporzed corundum, deposited in a vacuum, much like coating a lens. The Gemoogical Institute of America volunteered o test a stone treated by this process for ardness, refractive index, etc., but the ompany would not permit the test. We o not know whether "sapphirizing" is till being done.

Identification of Titania is largely by ght. There is no natural mineral equivlent. Natural rutile, usually opaque, or ccasionally of very deep red, never pproaches the appearance of the synhetic. No other gem material has the xtremely high dispersion or birefrinence of synthetic rutile. Like other synhetics which crystallize from a liquid pon a reduction of temperature, rutile apt to have spherical gas bubbles. hese are visible only with a microscope. hey are usually quite small and widely eparated.

The professional cutters of Titania y to orient the stone for cutting so hat the table is at right angles to the rection of single refraction. The stone en appears singly refractive when ewed through the table. If this is not one, the strong double refraction lends fuzzy appearance to the stone.

Strontium Titanate

Strontium titanate, first called Starilm, now Fabulite, although technically ot a synthetic, will probably always be called in the trade. Made by National ead Company by a process similar to at of Titania, its composition differs om Titania only in the addition of rontium.

The resultant material is practically lorless, of very high dispersion (.190), ut only 6 in hardness. It is very beauul material, probably more nearly transparent than Titania. Fabulite is said to be very difficult to polish and has never been sold in the rough. It is a very fine looking gem material.

The identification of strontium titanate should be easy. It is singly refractive and very heavy (S.G. 5.13), one-and-a-half times as heavy as diamond. After a little experience it should be easily identified by merely hefting in the hand.

Due to the difficulty of polishing, facet junctions may appear rounded. The R.I. is 2.049, just below that of diamond and well over the top measurement possible on the refractometer. As in all boule synthetics, spherical gas bubbles are common. Dispersion (.190) is four times that of diamond. The color, a light yellow, is very close to colorless. The color, or absence of color, is completely masked by the high dispersion. It has no natural mineral equivalent.

Rock crystal quartz is made synthetically but may never enter the gem market. It is made by a non-secret hydrothermal process, possibly quite similar to that used in making synthetic emerald. The quartz is used for electronic frequency control crystals and other scientific purposes. It is much too costly for use as gem quartz. It is said that there is no method of differentiating between the synthetic and natural quartz.

Some mention should also be made of the many so called synthetics such as "synthetic alexandrite," "synthetic tourmaline," "synthetic peridot," and "synthetic zircon." These gems are actually either synthetic corundum or synthetic spinel of a color somewhat similar to that of the natural mineral in the name. Many of these make fine looking stones that may be superior in both appearance and durability to the natural gem. But they are still synthetic corundum or spinel.

Chapter 14

Imitation Gem Stones

Frequently indeed, will the gemologist encounter the many and varied forms of gem stone imitations—substitutes, simulated, reproductions, manufactured, assembled, composite, altered, doublets, triplets, and on the fringes of the imitation category — stained, heat treated, and bombarded stones which are imitation in color only.

The Egyptians made imitation gem stones of glass a thousand or more years before Christ. The Romans found many ways of imitating true gems, some of very fine appearance. Of course, modern man has improved on every method and invented many new ones.

Imitation stones are not always made with intent to deceive. Many are produced which are truly decorative in appearance and do not closely simulate any natural stone. Others may be made and sold as inexpensive substitutes for the real thing, although synthetic gem materials would seem more practical for this purpose.

The words *imitation* and *substitute* are inclusive terms, covering any gem material used in lieu of a more valuable gem. Ordinarily, when speaking of imitations, we think of glass gems. But many other materials are used for the purpose.

The terms imitation and substitute are seldom used in the jewelry trade, not having sufficient sales appeal for the average buyer. Jewelry stores prefer the terms "manufactured," "artificial," or "scientific gems." Also, the terms *paste* and *strass* may be used for stones of glass.

The word "*simulated*," while having the same meaning, is used mostly by the mail order houses. "Sparkling simulated birthstones!"

Glass

Glass, as commonly used for windows and similar purposes has a somewhat variable composition, is approximately silica 75%, soda 14%, lead oxide 10%, alumina 1%. Glass of this approximate composition is called *crown glass*, rather low in refractive index (R. I.), 1.44 to 1.55; dispersion .016. Crown glass is used for the cheaper gems where dispersion is not a requirement.

Glass of much greater dispersive power, called variously *flint glass, lead glass*, or *strass*, has a composition approximately of silica 40%, lead oxide 51%, potash 8%, alumina 1%. The R.I. varies from 1.57 to 1.68. It may be higher, but not for gem material. Dispersion is normally .036 but may be as high as .041, which is just short of diamond (.044). Zircon is .038.

The addition of lead to glass, while it raises the dispersion and R.I., also greatly lowers the hardness and durability. If sufficient lead is added to give an R.I. of 1.70 or over, the hardness drops below 5, making it impractical for jewelry use. This is done when glass is made for the hemispheres of refractometers used in gemology. The R.I. of this glass is 1.86 and the hardness about 4½.

Color is added to glass by the addition of suitable metallic oxides, very much as nature adds them to her minerals. Blue results from cobalt and a little manganese, green from chrome and copper oxides, red from a very small percentage of gold chloride, yellow from silver oxide. Probably each manufacturer has his own variations of these additions.

It is said that the master glass workers can produce glass with the color and textural appearance to creditably imitate any gem stone, except possibly opal. Glass may be very beautiful, but it lacks the other two requirements of a true gem—durability and rarity.

The identification of glass rests largely on its single refraction, lack of hardness, gas bubbles, and swirl marks, sometimes called flow lines. See Fig. 12-14. Its wide range of possible R.I. and S.G. makes these factors of little use in identiication except that seldom indeed is glass found to have all three factors—appearance, R.I., and S.G.—of a particular gem stone. It may have two of these but almost never all three. For instance, a glass imitation of amethyst might have the proper color, and R.I. of .55, but its S.G. would probably be .10 instead of the 2.66 of amethyst.

Glass gems, other than expensive replicas, are usually molded. Unless the facets have been individually polished, concave facets are often seen. Protruding edges of glass may be seen on the girdle as the result of worn or imperfectly fitting mold junctions.

The softness of glass gives the nongemologically minded jeweler the common test of touching the girdle of a stone suspected of being glass with a sharp corner of a broken tipped file (hardness 6). If he can feel it "bite," he will consider it glass.

Several years ago a jeweler and rock shop owner had a sales booth at a gem show. Having some spare time, he was testing a pile of old jewelry stones. His method of testing was to try to scratch each stone with the sharp corner of a piece of tourmaline, hardness 7½! Two knowledgeable amateur gemologists watched him for a while, then asked what he was doing. He said he was testing for glass, which he was going to throw away. He had already tested many stones and had a small pile of "genuine" stones and about a coffee cup of "glass." The two rockhounds offered to relieve him of the cup of stones but finally had to pay him $5.00 for them.

Later, on testing the stones in the author's laboratory, they found one or more gems of apatite, idocrase, nephrite, hessonite, citrine, peridot, and one stone each of benitoite, sinhalite, and demantoid. And, of course, plenty of glass. What the dealer had kept was largely the synthetics. We have often wondered where he learned about gem testing.

Plastic Gems

In modern jewelry of the cheaper class, plastics are very frequently used. Transparent, translucent, or opaque; all colors; all cuts. In general, plastics are molded and if a stone of the faceted type is held toward a light, concave facets may be seen. Large bubbles are common. Small bubbles and some angular impurities are often seen when examined under the microscope.

If the stone is unmounted, hefting it in the hand will usually reveal its feathery lightness. The S.G. of plastics used for gems is in the range of 1.15 to 2.20, much lower than any gem it might simulate other than amber.

True amber (S.G. 1.08) is lighter than plastics. If a saturate solution of table salt and water (S.G. 1.15) is used as a heavy liquid, amber will float and plastic will sink.

There are rather many varieties of plastics but only a few are used for gems. Their R.I., generally near 1.50, may reach 1.70 for bakelite.

The hardness of all plastics is lower than the natural gems, running, according to variety, from 1½ to 3 on Mohs' scale, most commonly about 2. A fingernail (H. 2½) will scratch or dent most plastic, a copper coin (H. 3) the harder varieties.

Composite Stones

Next in interest are the assembled or composite stones. The varieties are *doublets, triplets,* and *foil backs.*

Assembled stones are classed as imitations even though some are made of natural minerals. When made up of natural minerals they are termed *genuine doublets,* or *genuine triplets.* These are not common. Occasionally there may be a genuine foil back.

Doublets are made up of two sections of material, a top and a back, cemented or fused together. The parts may be the same or of different material, generally the latter.

The most common of all doublets, although no longer made, is the garnet topped doublet. Fig. 14-1.

The red garnet top gives a hard, wear-resistant surface, but being thin, lends no color to the stone. The stone's color results from the glass back. Stones of this type may have the red of ruby, the blue of sapphire, the green of emerald, the yellow of topaz, or even be completely colorless, and still have the red garnet top.

One of these doublets showed up at a

gem show where we were testing gems for the public. A stylishly dressed, elderly lady had watched us testing a series of synthetics, then finally said, "Would you like to test a good stone, for a change? I have had this stone many years. It was valued for me by a New York jeweler at $1200.00, but I would not sell it for that." She handed me a nice looking, yellow gold ring, the mount rather worn, with a fine colored emerald green stone of about three carats.

I set the ring in the Gemolite microscope expecting to see some nice 3-phase inclusions. But I was surprised to see the oriented needles common to almandite, and a distinct plane of bubbles at the junction between the garnet top and the glass back.

She must have noticed my change of expression. She said, "Don't tell me it's glass because I had it tested by an *expert* in New York when I had it insured."

Her emphasis on the word "expert" rankled a little. He must have been a real expert.

Her husband, just behind her, was appearing amused, so I asked him if they really wanted to know what the stone was, or should we just forget the whole thing. He said, "Go ahead and tell her. I'm stuck for another stone, if it's not emerald."

So I told her it was a doublet and explained that it was about 10 per cent red garnet and 90 per cent glass. I showed it to her under the microscope and showed her a garnet with the same type of inclusions. I borrowed a small emerald from a dealer at the show and let her see the completely different inclusions. She was convinced — but not happy. They had paid insurance premiums on the supposed value of the ring for 21 years.

Doublets

Doublets, like other imitation stones, are not always sold to deceive. Before the advent of synthetics, and when European labor was very cheap, they were made to serve several purposes. They offered a longer-wearing surface, a stone of very fine appearance and color, and a stone much cheaper than the least valued ruby, sapphire, emerald, or topaz.

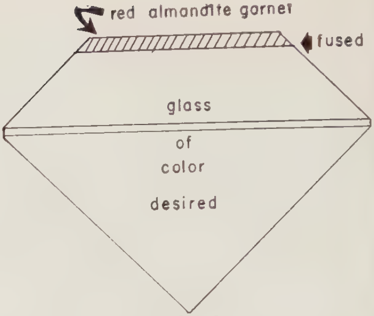


Fig. 14-1

Another gem stone often seen in doublet form, and for a much better reason, is opal. Much of the rough opal, when found, is in thin, almost unusable form. In Australia, source of most of the world's best opal, many of these thin pieces of opal are cemented to a backing of dark obsidian, opal matrix, or a dark variety of chalcedony. Fig. 14-2. The backing is usually very dark or black, to darken the background and give the appearance of black opal.

Some very fine opal goes into these doublets, making splendid stones. They are often for sale in the larger rock shops for about $2.00 to $10.00 per stone and in some jewelry stores for about twice that amount. Their identification is largely in the appearance of the stone.

Another doublet, occasionally seen in central to southern areas of California, is the synthetic sapphire-synthetic rutile doublet. Fig. 14-3. These fine appearing stones were made by Mr. Daniels of the M.D.R. Manufacturing Co., of Los Angeles. The synthetic sapphire, always colorless or a very light color, offers a hard, durable wearing surface. The synthetic rutile is used for its unbeatable, fine appearance. Identify the sapphire top with the refractometer. Use a microscope or loupe to see the junction plane and possible bubbles in the synthetic rutile.

One occasionally reads of diamond doublets made in the same form, that is, divided at the girdle. They are very

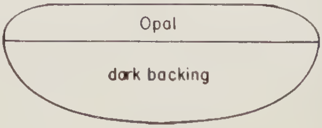


Fig. 14-2

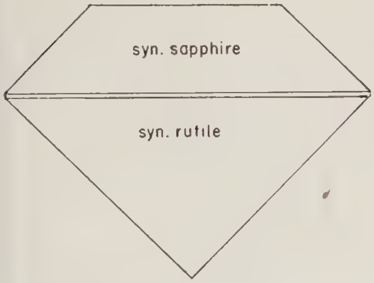


Fig. 14-3

arce, probably made in past years
en labor was cheaper, to utilize some
the smaller diamond slabs. We do not
lieve they are being made at the
esent time. A microscope would be
st for their identification.

Triplets

Triplets are stones where three sec-
ons of material are used. There are
ually two sections of gem material
d a central, colored section of plastic
cement. The stone's color comes from
center section. See Fig. 14-4.

In the past triplets were made to
itate emerald only. Quartz formerly
s used for the top and back; colorless
nthetic spinel is now preferred. Spinel,
th a hardness of 8, makes a durable
ne. In the jewelry trade such stones
called "Soudé emerald," "scientific
erald," or "Tecla emerald."

When identifying any doublet or trip-
, a check for refractive index on the
) and back may be sufficient if they
found to be different. A microscope
loupe to check for bubbles on the
ction plane is also excellent. But oc-
sionally there may be a stone with no
bbles on the plane of junction. If the
ne is immersed in a liquid of similar
I. to that of the stone, its character
will be apparent.

If the stone is viewed under ultraviolet light, long or short wave, the cement often will be noticeably fluorescent. The glass may also be fluorescent.

Doublets of the garnet-topped variety, if other than red in color, often may be identified by turning the stone's table down on white paper. A red ring will then be seen around the girdle of the stone.

If garnet-topped doublets of any color are held toward a light so the light is reflected from the crown facets to the eye, a noticeable difference in luster between the garnet top and the glass body of the stone will be seen.

About the middle of 1959 a new type of triplet simulating opal appeared on the market. It was reported by Dr. Edward J. Gubelin, Ph.D., C.G., F.G.A., in an article in the British publication, *The Gemmologist.*

It is found in two types. One is composed of a cabochon rock crystal (quartz) top, a very thin layer of white or black opal which is covered by a back of poor quality white opal. The thin layer of opal and the back are joined with a black cement, giving the stone a rather dark appearance.

The second type has a rock crystal top, a thin layer of white or black opal, and a back of black glass. Both have the appearance of black opal but Dr. Gubelin says both have a "wrong" appearance. The play of color being deep in the stone rather than at or near the surface should give reason for testing. If unmounted, the stone's assembled character should be evident. If mounted, a refractometer should show the R.I. to be that of quartz rather than of opal.

Foil Backs

Foil backs are glass or genuine stones with a backing of foil or lacquer to increase the brilliance or change the color. In this country, the term *rhinestone* refers to the colorless, glass foil backs so common in costume jewelry. Formerly the term was used for brilliant cut quartz gems cut in Germany. In Europe, at the present time, rhinestone refers to a novelty stone of multicolored glass. The colors red, blue, green, etc., are blended together to make a rather pretty

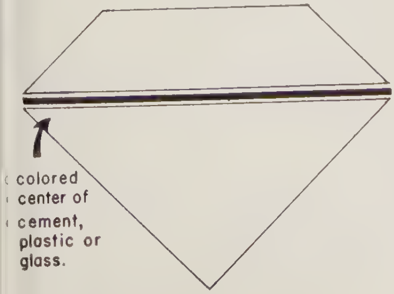


Fig. 14-4

stone but not an imitation of any natural gem.

Imitation opals that really look like opals have not been made yet. But an interesting tourist-quality imitation of opal is being made in Czechoslovakia. Two sections of glass are fused together after a thin varicolored metallic coating has been applied to the top of the back section. And, like an opal, they are difficult to describe.

Asteriated Stones

Imitation star stones are of two types. Star quartz, when correctly oriented and cut, with a colored mirror backing makes a creditable imitation of star ruby or star sapphire.

Synthetic ruby or sapphire cabochons may have a cemented backing of ruled or scribed bright metal or other material. The scribing is in three groups of parallel, fine lines, the groups at 60 degrees to each other, just as the needles are oriented in natural star stones. Or, the scribing may be done directly on the back of the corundum cabochon, then backed with a protective coat of opaque enamel.

These stones have a very distinct star but are easily distinguished from the natural by the action of the stars in reflected light. In natural stones the star is caused by oriented rutile needles from top to back of the stone, so the star is more or less stationary when the stone is tilted. In the backed synthetic, the star is caused by lines on the back of the stone only. The light must travel through the stone, be reflected from the lines on the back, and return through the stone to the eye. The bending of the refracted light causes the star to move around excessively when the stone is tilted.

Imitation Turquois

Other imitation stones occasionally seen are cabochons made from blue stained wood or bone, or porcelain with glazed ceramic colors to imitate turquois. I have in my collection a large "turquois" cabochon made of domed sheet silver, colored by glazed enamel. On close examination anyone can spot it as an imitation. But if the stone was mounted and casually examined, no one would think it other than turquois.

In past years inferior turquois has been dyed to an acceptable blue and sold in tourist-type jewelry. This turquois always had a rather porous texture and the dyed color looked dyed. Some softer minerals have been dyed and sold for turquois. The color of the dyed turquois and softer substitute is not permanent.

The present tourist-turquois market has been completely taken over and saturated by two somewhat different types of imitation turquois. Both are frequently called synthetic turquois but the term is incorrect.

One type is made from pulverized, low-grade turquois, chalky material ordinarily unusable for gems. The pulverized turquois with added coloring is mixed with a plastic and pressed in cabochon molds. Sometimes black material is added to give a very good turquois matrix effect.

The second type is a manufactured gem made with approximately the same composition as natural turquois and pressed in cabochon form. This type is a little harder than the plastic bonded type, about 3½ on Mohs' scale.

Both of these imitations have good turquois color, are hard enough for practical tourist jewelry, and the color is permanent. They would seem to be an improvement over the older types of imitation turquois but whether they are superior to the better grade of glass imitation turquois is a matter of opinion.

Heat Treatment

Many gem stones have acquired a salable color through heat treatment. Probably the best known of these is zircon. It is said that all zircons regularly offered for sale in the jewelry trade have been heat treated.

The stones as brought from the mine are placed in a crucible and heated to a red heat for some time in an open fire. After cooling, those with a satisfactory color are removed. The balance is reheated in a closed stove with very little oxygen. Again, after cooling, those with a satisfactory color are removed. The remainder, with unsatisfactory colors of brown, blue, or dingy white, are probably offered for sale to amateur cutters or as mineral specimens at relatively w prices.

There are other versions of the heat
eating processes, some involving chem-
als, but these methods seem to be
mething of a trade secret. Most zir-
ns come from Indo-China near Siam,
d their treating processes have given
tisfactory results for a long time.

Many heat treated stones acquire a
ermanent color, but not all. Some of
e finest white or colorless zircons may
se most of their brilliancy and dis-
ersion, some even turning a light
own, after a few days or months. A
ir percentage of blue zircons will turn
own after a few months.

There seems to be no way to tell
nich of the colorless stones are apt to
se brilliancy. But, of the blue it is
id that those with even a slight tinge
brown in the blue are the ones most
kely to change.

Most amethysts will change color after
eating. The extent of the change and
e final color seem to depend upon the
urce, just what mine it came from.
nethyst from a certain mine in Brazil
anges to a light green, some merely
rn lighter, others will change to light
dark citrine.

Some citrine and yellow smoky quartz
ll alter to a golden yellow. Most
noky quartz can be lightened by merely
lding the stone in the flame of an
cohol lamp, watching the color, and
moving it from the heat when the
ade is satisfactory.

Topaz from certain Brazilian mines
ll change to pink after heating. Some
lden beryl will alter to an aquamarine
lor.

Tigereye, a pseudomorphic variety of
ystalline quartz, is a natural golden
llow. Proper heat treatment changes it
a deep red. An acid and heat treat-
ent results in a deep blue.

Of corundum, ruby changes to a
ngy green when hot, but regains its
d color when cool. Sapphire of most
lors, if well heated, will be colorless
en cool.

When the above changes of color fol-
wing heat treatment are permanent,
processes are not considered un-
nical, nor the stones imitation. It is
rtain that almost every gem stone we know has been heat treated by nature in some manner, at some time, during its existence. It seems only logical that man should use this practical means to enhance a stone's appearance. Heat treating can sometimes help the color, even as cutting adds to the brilliance.

Chemical Dyeing

Chemical staining of gem minerals is mentioned in many books but is seldom attempted by the amateur. A San Diego rockhound, after reading everything available, has been experimenting with it for several years and is just now beginning to get some reliable results. It is a slow process so experience comes slowly.

Only those minerals that are porous to some degree will accept the stain or chemical treatment. Although they look very solid, chalcedony, agate, and jasper are the materials most commonly color treated.

Not all agate will take the color. Stratified chalcedony, of various degrees of gray to white, when treated, will accept an amount of dye differing with the porosity of each layer. Some layers may not take the dye at all, remaining completely white. Pure chalcedony is quite porous. Opal is not porous. The more completely opalized the layer is, the less it will take the dye. Artificial coloring of banded agate, making some bands pure black, the others remaining snow white, makes possible the finest cameos where a carved face of white material is raised above a glossy black background.

The stone most commonly stained is the so called "black onyx," which is used extensively for intaglios and other men's ring stones. The process is one of impregnating the uninteresting gray chalcedony with a solution of honey or sugar and later treating it with sulphuric acid which turns the sugar to carbon.

"Swiss lapis" is jasper stained a deep blue. A great deal of this material is processed in Idar-Oberstein, in Germany.

"Green onyx" is stained chalcedony. It is too dark and too intense. Real chrysoprase is an apple green. Many other colors of stained chalcedony are possible but are not common in the jewelry trade.

Occasionally seen are "crackled"

stones of quartz or synthetic corundum. The process is that of heating the stone quite hot, then dunking it in a dye solution. Many fine cracks are developed by the rapid cooling of the stone, and the dye filters into the cracks.

With rock crystal (quartz), the process is used to give a unique or unnatural appearance and color to the stone. Synthetic ruby or sapphire, being already colored, the effect is that of a highly flawed natural stone.

The identification of artificially stained or dyed stones is largely by their appearance. Most colors achieved by staining never really simulate the true colors of nature's processes. For instance, nature very seldom produces a fine black chalcedony, so any "black onyx" encountered must be accepted as dyed. "Green onyx" is of a color not found in nature, as is also the dyed "chrysoprase." They are too dark and the color too intense.

The acquired color of chemically stained stones cannot always be detected under a microscope or by other gemological tests.

During 1957 artificially colored jade appeared on the market, the color a rather fine green. The process was traced down by the eminent dealer and writer on the subject of jade, Martin L. Ehrmann, C.G. The Chinese process is a simple one using some heat and an acid base dye on whitish gray jadeite. The color is good and apparently permanent. A similar process has been used on chalcedony but rapid fading in sunlight makes it impractical.

Another, and more effective method is also used on jade. This method uses a triplet consisting of a concave cap of fine quality translucent white jadeite about one-half millimeter thick, a smaller cabochon ground to fit into the hollow cap, and a very thin backing to cover the bottom of the stone. The center piece is covered with a green jelly-like dye, pressed into the cap, and the thin back cemented on. The result is a cabochon of the same color and appearance as the finest imperial jade. This type when unmounted is evident by the seam near the bottom of the cabochon. The Gemological Institute of America says the spectroscope and microscope will identfy them.

Radiation Treatment

In the past few years considerable experimenting has been done toward altering the color of gems, particularly diamonds, by exposure to the emanations from radium, X-rays, and atomic bombardment in a cyclotron. Radium and X-rays caused color change but only after rather long exposure and the colors resulting are usually not permanent.

The cyclotron has given a more permanent color change, but even so it may be lost after nominal heating. Diamonds of a cape or light yellow color, after bombardment by the cyclotron, acquire a rather lovely, slightly olive green color. This is not merely a hint of green, but a fine medium green and they still look like diamonds. We have seen several stones up to two carats in weight and thought them very beautiful. The total cost is about half or two-thirds that of a high-grade, colorless stone.

Chapter 15

Fashioning Gem Stones

The beginnings of the fascination and ppreciation of gems is lost back in the era of the beginning of man. True, he did not have our modern scientific gem utting techniques which bring out the maximum in brilliancy and color disper- ion, making our gems shimmering ob- ects of beauty and a pleasure to wear. ut ancient man was able to appreciate he beauty in the semipolished, water- orn pebbles of gems which he first ob- erved glistening and flashing colors in he water of the stream beds. Ancient man and his mate probably started the ad of wearing precious gems when they ere attracted to these pretty colors and icked them up to admire at leisure in heir cave.

As time passed and the brain of man eveloped, he began to observe more nd more of the things around him. He ot only remembered them but also arted to improve them. The semi- olished stones intrigued him and he set bout finding what caused the polish hich he found only on the stones in he stream beds and to try to duplicate nd improve on this polishing method.

Next he probably had to find a way wear the gems. A hole was drilled they could be strung on a cord and orn around the neck. Here the differ- ce in hardness of the various gems was scovered. Man noted the fact that it ook a sliver from a stone of greater ardness to drill a hole in a stone. And, doubt, that the diamond, king of gem tones, would drill them all.

When this first difficulty was over- ome, he did not stop but continued ntil the first gem stone with a sym- etrical design was produced in the gen- ral shape of our present cabochon cut tones.

The cabochon type cut does not have any faces (flat surfaces) on its sides. The only flat surface is the bottom or base of the stone. There are four cabochon shapes commonly in use. Fig. 15-1.

(*A*) *The simple cabochon.* Used for jade, moonstone, cat's-eye stones, agate, garnet, some emerald, and most ornamental stones. The ancient carbuncle, a cabochon-shaped red garnet, was cut in this manner.

(*B*) *The double cabochon.* This style of cut is used for the star stones. The Indian cutters, in most cases, cut with an excess of material on the bottom side of the double cab, to get more weight and more money for the stones. This cut is also used for light colored translucent stones to deepen the color.

(*C*) *Shallow double cabochon*, called the *lentil cut.* Often used for small pieces of gem material such as opal and moonstone.

(*D*) *Hollow, or concave cabochon.* Used to lighten the deep color of a stone, such as garnet. Emperor Nero is said to have had an emerald cut in this fashion, which he used as an eyeglass to get a better view of the games.

Next came jewelry settings to show off the stones to better advantage. With these also came the better type carvings. The faceted type stones probably started with the diamond, then later, other transparent stones were cut in this fashion.

The Diamond

The most precious of all gem stones is the diamond, the hardest natural substance known to man and the most beautiful of gems when properly cut.

The history of diamond dates from the years between 800 and 600 B.C. in

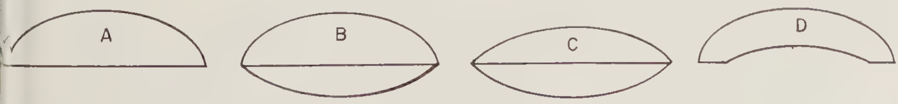


Fig. 15-1

India. For a period of about 2000 years all well known diamonds, such as the Great Mogul, Koh-i-noor, Shah, Regent, Pitt, and many other historic stones came from the Orient.

At that time diamond was the stone of royalty and was only worn by sultans, kings, queens, and others of very high rank. Many bloody battles were fought and kingdoms were lost for the possession of the gem of gems, the diamond.

The 15th century is very important, especially to the ladies, because at that time the wearing of the diamond passed from being worn by royalty only, to the more common people. This was accomplished by one of the glamour girls of the time, Agnes Sorel, a favorite of King Charles VII. She was able to talk the king into letting her wear some of his diamonds at one of his parties.

It is putting it mildly to say she created a sensation. This was the first time that anyone of less than royal rank had dared to wear these stones of royalty. And though she complained to him that the sharp edges of the stones hurt her delicate skin, she kept on wearing them at every opportunity.

The King's treasurer saw a great opportunity to profit by the excitement and envy of other women. He brought diamond cutters and jewelers from Venice and Constantinople to create fine jewelry for Agnes and other court ladies. They accepted this fashion in jewelry and it has stayed with us ever since.

A Symbol of Love

In the 15th century the diamond was also mentioned as the gem of the bride because it was regarded as a symbol of constancy, purity and innocence. The Greek name for diamond, *adamas*, meaning unconquerable, suggested the diamond as the symbol of an eternity of love.

Some of the ancients called the diamond the stone of the passion of love, for, like the flame of love, it sends forth a flame without the aid of any visible fire. The betrothal ring was, and still is, worn on the third finger of the left hand because it was believed that the vein of love ran directly from this finger to the heart. Many designs were used for this ring but the single stone or solitaire is now the accepted symbol and fashion.

Here are some interesting facts about early diamond jewelry.

In the year 270 A.D., Queen Zenobia owned and wore a diamond brooch. Charlemagne wore a diamond clasp. King Henry VIII had 556 diamond buttons (wow—where did he put them all?).

The first record of the use of the diamond in the engagement ring, is in a letter written in 1477 by Dr. Moroltinger to the future Emperor Maximilian just before his betrothal to Mary of Burgundy, daughter of Charles the Bold. It read: "At the betrothal, your Grace must have a ring set with a diamond and also a gold ring. Moreover, in the morning, your Grace must bestow upon the bride some costly jewelry."

Credit for discovering the art of diamond cutting belongs to the Indian diamond artisans centuries before the Europeans discovered the art. But to the Europeans belongs the discovery of symmetrical design in diamond cutting with which they were able to bring out some degree of the brilliancy and beauty which the diamond is capable of displaying.

The diamond cutters of India learned the art of diamond cleaving, and the fact that diamond powder was the only material that would cut and polish another diamond. They also were able to drill a hole through a diamond so as to be able to string it around the neck.

Tavernier

In the 16th century, Jean Baptiste Tavernier, famous world-travelling jeweler, reported that during his stay in India a large number of diamond cutters were using the method of cutting facets or faces on diamonds with diamond powder on a metal disc. The facets were not in any symmetrical design. They were also able to do engraving on diamond.

Louis de Berquem, of Bruges, one of the early European diamond cutters, is often given credit for being the first diamond cutter to discover the method of cutting the facets, but this more properly belongs to the Indian cutters. De Berquem did design and cut some of the first symmetrical cuts, such as the *endeloque*, a pear-shaped stone having table; and the *briolette*, which is a round shaped drop, heavy at one end, having no table facet but with symmetrical facets cut completely around the tone.

To de Berquem and the European cutters must be given the credit for cutting he diamond in a symmetrical design and placing the faces to bring out the hidden beauty of the stone. And it is through he combined efforts of the diamond cutters of Europe that the brilliant cut, hrough step by step and trial and error methods, finally emerged.

Evolution in Cutting

In India a large portion of the diamond rough was cleavages from large diamond crystals. These were polished just as they were or a few facets added o hide a defect of the stone. The first regular form of diamond cut was the *diamond point cut.* This was the natural ctahedral diamond crystal with the natural crystal faces polished and then set n jewelry. By natural evolution this diamond point cut was followed by the *diamond table cut.* This was the diamond point cut with a table and culet dded. See Fig. 15-2.

To those of you who do not know what is meant by a culet facet, we will xplain it this way. If the point at the nd of the pavilion of the stone (the bottom part) were to be left as a point, might catch on something or bump against some solid material which might asily cleave and ruin the stone. So this point is ground down a bit to form a mall facet to protect the stone.

Following the table cut, next came he *Mazarin cut.* Today we know this the *single cut.* It is the same as the able cut but with the corners cut off both above and below the girdle. This ingle cut has eight equal crown facets and eight equal pavilion facets, a table and culet, a total of 18 facets. See Fig. 15-2. Cardinal Mazarin is given the credit for the design of this cut and the *rose cut.* The rose cut is like a round cabochon with a faceted top, looking like one-half of a bead.

We can begin to see the gradual change, the increase of symmetry, as the diamond point cut evolved into the full 58 facet brilliant cut. Also, the approach to perfect roundness and the use of correct angles. In 1650 facets increased to 34. Just before 1700, 50 facets were used.

In the year 1700 the diamond brilliant approached closest to our modern brilliant when the Venetian diamond cutter, Vincent Peruzzi, first cut a stone having 58 facets. There were 33 on the crown, including the table, and 25 on the pavilion, including the culet.

Although they had arrived at the correct number of facets for the brilliant cut, they still had not solved the problem of correct angles for the facets. Nor had they found that perfect roundness was needed to bring out the maximum in brilliancy and dispersion displayed by our modern, properly cut brilliants.

The evolution of the facet angles is interesting. Starting with the natural octahedron or diamond point cut, the angle with the girdle was about 55 degrees. The angles for the earlier single cut were 50 degrees. Peruzzi's 58 facet cut was at 45 degrees for crown and pavilion. The modern American brilliant cut has main facet angles of 34½ on the crown, and 40¾ on the pavilion.

Here is a quotation about facet angles from a very famous historical book, "A Treatise on Diamond," by John Mawe, published in London, 1823: "The inclination of the facets to the girdle ought to be 45 degrees, and the bizel should be

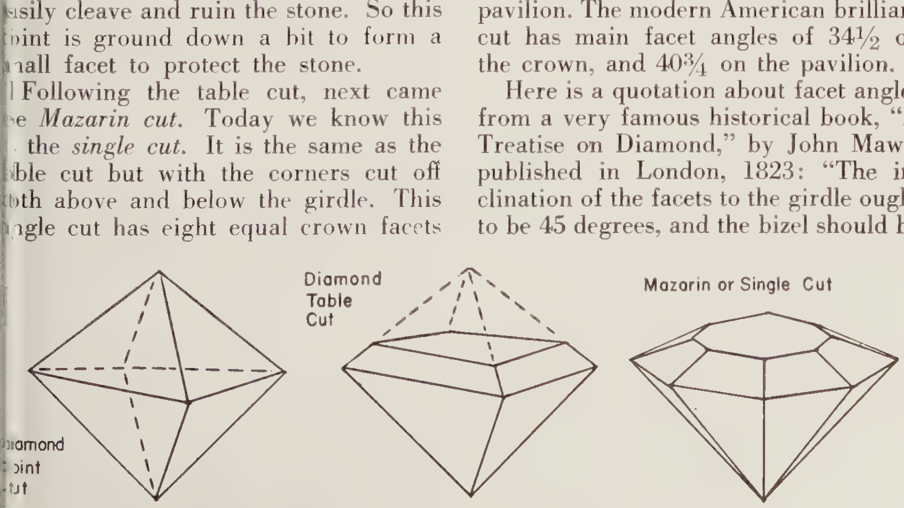
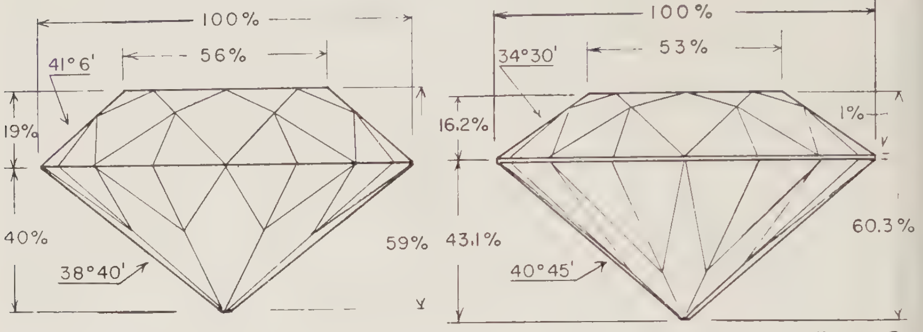


Fig. 15-2

Fig. 15-3. **STANDARD BRILLIANT CUTS FOR DIAMOND**



European Brilliant Cut **American Brilliant Cut**

inclined to the table at the suplement of the same angle. (Crown and pavilion at 45 degrees.) Many of the foreign cut brilliants have the facets inclined at an angle of 50 degrees, or even more, the principal study with the foreign workmen being to retain as much weight as possible. Those stones are sometimes reduced to the above standard (45 degrees) by English artists, it being found that the expense in recutting the facets and the consequent loss of weight. is fully compensated by the increased brilliancy of the gem."

Many of the diamonds cut this way are today known as "Old Mine cut," because they were cut to save as much as possible of the original diamond as it came from the mine. They are spoken of as "Old Miners" and if recut to conform to our modern brilliant cut standards, even though the stone is smaller in size, will be more valuable because of the increase in brilliance, dispersion and beauty.

Standard Brilliants

The modern European standard brilliant was for some years considered to be the ultimate, the perfect brilliant, with angles of 41 degrees 6 minutes for the crown; 38 degrees 40 minutes for the pavilion mains. These angles were calculated by the German scientist, W. Fr. Eppler, upon the basis of maximum return of light to the eye from all rays striking the crown facets from a *vertical direction.*

Presently accepted is the American cut, worked out by trial and error by a Boston diamond cutter, Henry Morse, and later calculated by Tolkowsky on the basis of maximum return of light to the eye from rays of light striking the crown facets from *all possible directions.* Tolkowsky's figures were found to match almost exactly the trial and error angles of Morse. See Fig. 15-3.

Swindled stones are those that are not cut to correct proportions or angles for the perfect brilliant. Such stones may be cut with a very wide table and very shallow to give it more spread. Or they may be cut very much deeper to save material. In either case the result is a lack of brilliance and an absence of dispersion. See Fig. 15-4.

Correct pavilion angles give maximum brilliancy, while correct crown angles make for maximum dispersion. No gem can reach maximum value per carat if it is not correctly cut.

It will be found that the more ethical jewelry stores, often with an American Gem Society decal on their window, and very many of the small community jewelers do not handle the swindled, incorrectly cut diamonds, and will give better value for their customers' dollar. There is an axiom in the jewelry trade—"*There are no bargains in diamonds.*"

All of the various cuts we now know have originated from three simple forms—the round brilliant, the square cut, and the oblong style cut which we commonly call the emerald cut.

Cuts that have evolved from these three basic cuts, but retain some of their appearance or outline, are called variations of that cut. Or it may be called a modification of that cut. If a cut stone is round, but has no specific name, it may be called a "modified brilliant."

Where the style of cut is so altered that it bears no resemblance to any of the three main cuts, round, square or oblong, it is called a *fancy cut*. Most of these variations and fancy cuts have individual names, such as *marquise*, *Portuguese cut*, *briolette*, etc. But as we are not trying to teach cutting, we will not mention them in detail.

Diamond Cutting

Since the diamond can be cut and polished only by the use of diamond powder, the procedure in the cutting of a diamond brilliant is different from the cutting and polishing of other stones.

There are five steps to bring the rough diamond crystal to the finished brilliant form. The planning, cleaving or sawing, bruting or rounding, lapping or blocking, and brillianteering.

The planner is the diamond expert who carefully studies each stone and decides whether it is to be sawed and where, or if it is a large stone, whether it should be cleaved. He also decides what style cuts should be made from the crystal.

After the planner makes his decision, he marks the stone where it is to be cleaved or sawed and sends it to the next man for the job. If the stone is to be cleaved, the cleaver scratches a groove along the mark made by the planner. He inserts a metal wedge in the groove and strikes it with a clublike hammer. This splits the diamond along the "grain" or cleavage plane.

In sawing the diamond, the stone is attached to the end of a metal dop by the use of a soft metal (solder). The dop is then placed on a weighted arm against a revolving saw blade. The blade is of surprisingly thin phosphor bronze, .004 of an inch thick and about four inches in diameter. The blade is charged initially with a mixture of diamond dust and olive oil by a metal roller. As the cutting proceeds the blade is charged from the diamond it is cutting. Sawing a two-carat stone may take from five to eight hours.

Sometimes the blade hits a "knot." which is another diamond crystal differently oriented from the crystal enclosing it. As diamond can be sawed in only one crystallographic direction, the knot twists up the saw blade and the diamond must be sawed from the opposite direction until it again strikes the knot, after which it can be broken to complete the cut.

After sawing, the diamond goes to the *bruter* who takes the sawed crystal and rounds or preforms it to a circular form. The stone is held in a lathe and centered. The bruter rounds it down with another diamond secured to the end of a stick, much like half of a billiard cue or a broomstick, one end of which he holds under his arm for steadying. Diamond is not actually cut but is rounded by breaking off tiny fragments or chips. These are caught in a cup and saved for use in other stages of the cutting.

Next, the diamond is passed to the *blocker* who cuts and polishes the table and the eight crown main facets and the eight pavilion main facets. The stone then goes to the *brillianteerer* who cuts the smaller facets and finishes the stone.

The cutting and polishing of the diamond facets are done with diamond dust and olive oil on a finely grained cast iron lap.

Faceting Other Stones

The faceting of other gem stones is simple compared with cutting and polish-

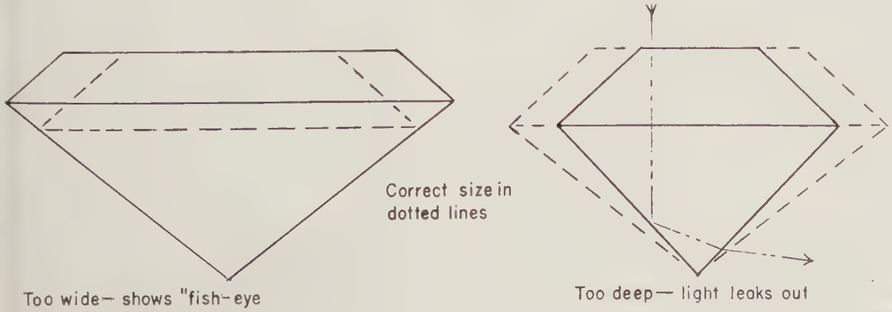


Fig. 15-4

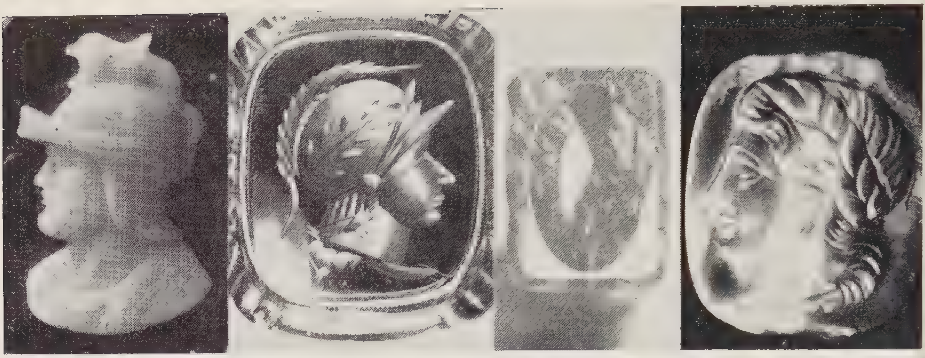


Fig. 15-5. Left to right: a cameo, an intaglio (machine cut), a chevee, and a cuvette of tigereye (very old).

ing the diamond. The use of diamond powder is not necessary but it is often used when cutting corundum and other hard stones. The sawing process is also very different. The blade used is of thicker material and has diamond powder around the rim of the blade, held in small slits in the metal. In some blades the diamond powder is bonded or "sintered" around the entire rim.

Blades 12 to 18 inches in diameter are used for slabbing. Six- to eight-inch blades are used for trimming during which the slices are hand-held on a flat table.

The stones may be preformed or rounded to required size by hand or in special preforming machines. Either method uses a silicon carbide, medium or coarse grit, grinding wheel well trued. The stone is then secured to a metal dop with special dopping wax and the dop inserted in the chuck of a faceting machine.

Such faceting machines, often called facet heads, are arranged with indexing mechanisms for properly placing the facets at intervals around the stone and for holding the stone at the proper angles for each facet. The cutting of facets is usually done with diamond impregnated laps. Polishing is accomplished on flat laps of various metals and materials with polishing compounds of various kinds. Type of lap and polishing compounds depends upon the stone being cut. There are many makes and varieties of facet machines, all good, but of course, all different.

Carved Stones

Another form of jewelry stone is the carved or engraved gem. This type was very popular in early Greek and Roman days. The scarab of Egypt, circa 2000 B.C., is another example of carved gem. Today most stones of this type are carved by machinery.

The *cameo* is a raised figure, carved above its background. Shell is often used, as well as several varieties of chalcedony. It is really a bas-relief sculpture in miniature.

Intaglio is the name given to carvings where the figure is carved *into* the background, depressed below its surface.

Chevee is a flat topped gem stone with a concave, oval depression in the center.

Cuvette might be called a combination of the chevee and cameo. It has a raised figure carved in an oval depression. Usually the rim around the carving is as high as the figure. See Fig. 15-5.

Many indeed are the imitations of the various types of carved gems, imitations in glass, plastic and ceramics. Many are of the assembled type, with the figure and the contrasting colored background moulded separately and cemented.

As to identification of genuine or imitations, standard tests apply. The appearance is often sufficient to identify. A microscope will usually show up an assembled carving.

Ceramic cameos are often very beautiful. They are not usually made with an intent to deceive. As they do not often simulate a natural gem stone they are not classed as imitations. Josiah Wedgwood, famous English pottery maker, was the first to make these cameos from pottery. They are still made and are called Wedgwood cameos.

Chapter 16

Magnification

With this chapter we start the study of the more practical aspects of gemology. We will describe and explain the theory of the various gem testing instruments and the methods of using them.

Again let us emphasize the value of rereading and restudying the previous chapters to make those to come more understandable and therefore more valuable and interesting.

Magnification in various forms plays an important part in gem identification. A simple lens forms the eyepiece of the refractometer to magnify the scale. The dichroscope includes a lens in the eyepiece to magnify the image seen through the instrument. A magnifier is often used with the polariscope to aid a search for optic figures. Magnification of inclusions often directly aids in the identification of a mineral and makes possible the separation of natural and synthetic gems.

Magnifiers

The simplest form of magnifier is probably that known as the jewelers' loupe. Fig. 16-1. It contains a single, uncorrected lens, as a rule, and is capable of magnifications of from 1.5X to about 7X. Uncorrected lenses have certain disadvantages. Spherical aberration causes some distortion as the center and the outer part of the field of view never quite focus together. Chromatic aberration causes color fringes around the object viewed. Loupes cost from about $1.00 to $5.00, according to quality and magnification. There is also a binocular loupe, the Magnifocuser, available for around $12.00.

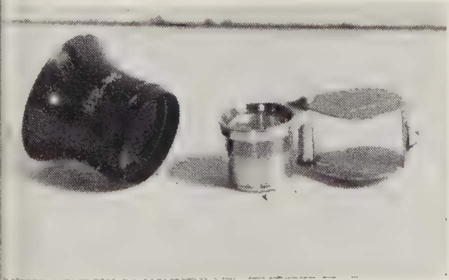


Fig. 16-1. Jeweler's loupe (left) and pocket hand magnifier of the triplet type.

Better magnifiers are made in the form of doublets and triplets and various variations of these. In the doublet, the two lenses are "air-spaced" and give a reasonable amount of correction for both spherical and chromatic aberrations. In the triplet, the center lens supplies the magnification and the front and back lenses correct the spherical and chromatic aberrations. The best quality triplets of 7½X to 14X (the most practical sizes, with 10X the most used) cost from $12.00 to $15.00. See Fig. 16-1a.

Another popular magnifier that is better than the doublet but not quite as good as the triplet is the Coddington lens. This is one thick piece of glass with a "stop" ground into the center. This is not a triplet but is very good for general use and the cost is from $3.00 to $8.00. See Fig. 16-1a, B.

Corrected lenses are made up to 30X, but above 10X they are extremely difficult to use because their very short working distance makes it difficult to illuminate the object to be viewed. The higher powers from 20X to 30X are also considered very hard on the eyes if used extensively.

The focal length of a magnifier and its magnification are directly related. A 10X magnifier has a focal length of one inch; a 5X, two inches, etc. Divide 10 by the focal length to get the magnification, or, divide 10 by the magnification to get the focal length.

Considerable practice is necessary for

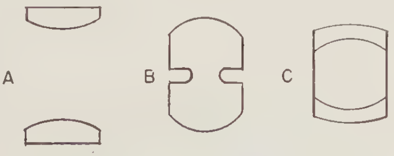


Fig. 16-1a. Lens arrangements of hand magnifiers. A, an air-spaced doublet. B, a Coddington magnifier. C, a typical triplet arrangement.

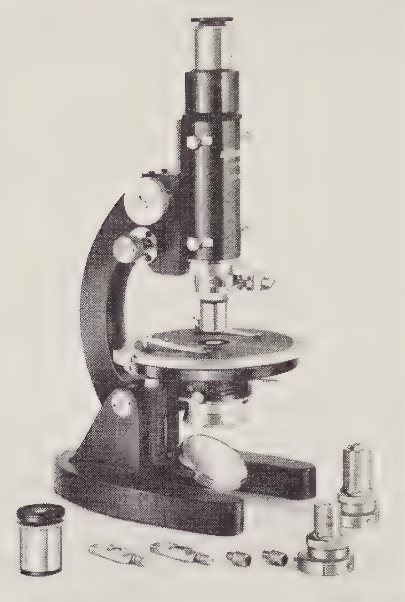


Fig. 16-2. A monocular petrographic microscope (polarizing) with some of its many accessories.

the proper use of a magnifier. It is not only necessary to become accustomed to the focal length of the lens, but proper illumination of the object is sometimes difficult and always important. Light should strike the object from the side and top. The stone or object must be held so neither the viewer's head nor the magnifier will cause a shadow. A good system is to hold the stone near the edge of the reflector of a gooseneck lamp so that the light strikes the stone but not the lens.

Microscopes

Magnification of gem stones and their inclusions, if over 10X is required, is more effectively accomplished with a microscope. Also, when any extended observation at 10X is required, a microscope will prove more efficient and easier to use.

Many varieties of microscopes, all more or less suitable for gem stone examination, are available. There are two basic types, monocular and binocular.

Monocular microscopes have a single tube and only one eye is used. The petrographic or polarizing microscope, much used by mineralogists and petrologists, is of this type. See Fig. 16-2. Also, many of the cheaper and moderately priced biological or medical microscopes are monocular. Some of these, with objective lenses and eyepieces of low power can be adapted for viewing gem stones if there is sufficient working distance between the bottom of the lens and the table.

This type of microscope is known as a compound microscope because it uses two lenses. The objective lens, nearest the object, projects a magnified image of the object to some point inside the tube, near the top. The eyepiece or ocular is set to view this image and magnify it further. See Fig. 16-3.

The total magnification of a compound microscope is figured by multiplying the powers of the objective and the ocular. If the objective is 2X and the ocular is 15X, the total power or magnification will be 30X. This applies only to standard microscopes with the standard tube length of about 160 millimeters. This length can be varied slightly and in standard instruments may vary from 150mm to 180mm. If the tube is appreciably longer or shorter, the calculation for power will not hold if standard optical components are used.

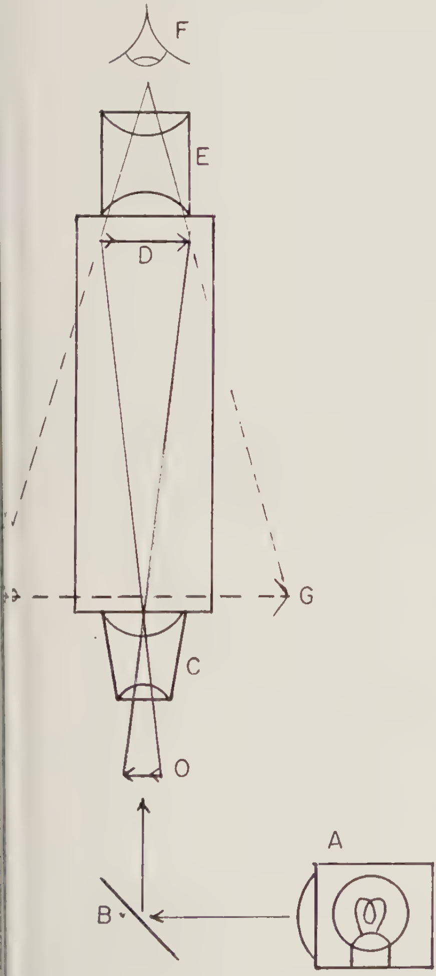
Monocular microscopes, unless specifically designed for the purpose, are never wholly suitable for gemological work. Most of the cheaper Japanese and German instruments, costing from $10.00 to $50.00 are quite useless for the purpose as they have been mainly designed for high-power biological work. The objectives and working distance are usually very short and the field of view very narrow. Illumination methods used with these instruments are not satisfactory for gem examination.

We know of only one monocular microscope especially designed for gemology. It is made by Rayner of London. It is available through Kenneth Parkinson, 11 Fitzroy St., Hull, England. The instrument costs about $300.00 including import duty. It is probably the most thoroughly specialized microscope designed for gemology. It does just about everything except put out the cat when it's time to lock up at night. But it is still only a monocular instrument.

Binocular Microscopes

A binocular microscope has many mportant advantages over the monocular type. It has two tubes, permitting he use of both eyes and giving stereoscopic vision. Those intended for use in gemology have a wide field of view permitting inspection of a much larger area for a given magnification.

To make possible a variation of magnification, oculars and objectives should be easily interchangeable. Objectives on the best instruments are arranged to slide or rotate to change from one to the other. Oculars on nearly all instruments are changed by replacing them as they slide easily in and out of the top of the tube without screwing or clamping.



. 16-3. The optics of a compound mi- scope and the typical method of direct mination from below. A is the lamp the nt from which is reflected by the mirror to and through the object to be viewed at The objective lens C forms a magnified age of the object at D near the top of the e. The ocular or eyepiece E views the eady magnified image at D and further gnifies it before it reaches the eye at G is the virtual image of the ocular and strates the total magnification.

For gemological work only three magnifications are necessary; 10X, 30X, and 60X or 75X, are the most satisfactory. Even in research work magnifications higher than 150X are seldom, if ever, used. This seems quite low when compared with the 500X to 1500X so common in biological and medical work.

Illumination

Proper illumination is of great importance in any work with a microscope. High magnifications and fine lenses are useless if the specimen is not properly illuminated to reveal the necessary detail.

There are two principal methods of illumination used in gemological examination — direct illumination and dark-field illumination. Most ordinary microscopes have a mirror below the

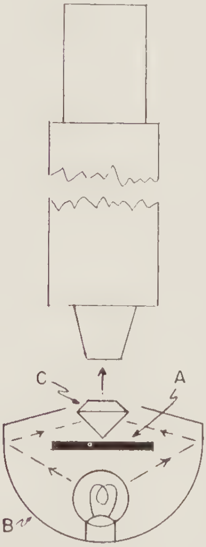


Fig. 16-4. A schematic layout of dark-field illumination as used for gem stone examination. The light from the lamp is masked from the object by the opaque, usually black, mask A. The light is reflected from the sides of the reflector B to illuminate the object from the side as shown at C. The image is then transferred to the eye in the same manner as shown in Fig. 16-3.

stage or table which reflects the light, from a separate lamp, up through the specimen and the instrument to the eye. This method of direct illumination from the bottom is used extensively outside the United States but it is not considered completely satisfactory for gem examination. See Fig. 16-3.

The method of dark-field illumination is more commonly used by American gemologists. The stone is supported above a dark background, light being directed into it from the sides only. This gives complete illumination of all inclusions or imperfections. See Fig. 16-4.

The difference between direct illumination and dark-field illumination is very marked. With direct illumination, inclusions appear dark or black, like silhouettes against a light ground. This shows little detail of the inclusions. On the other hand, with dark-field illumination, inclusions are lighted from the sides and top. This gives higher relief and the maximum detail that is possible with a lighted object against a dark background. Many smaller inclusions may be seen clearly with dark-field illumination that would be invisible with direct light.

Spherical gas bubbles in synthetic gem materials appear as dark spots by direct light, as tiny white illuminated spheres in a dark-field light.

When searching for curved striae in synthetic corundum, it is often advantageous to use at least some direct light. This can be done by placing a single layer of hand tissue, such as Kleenex, over the top of the dark field lamp housing, under the stone, to partially diffuse the light.

Some microscopes have a top light arranged to direct a spot of light on top of the stone. This is necessary when examining opaque stones and when observing the luster on small fractured surfaces. It is also excellent for examining mineral specimens. Two systems for top illumination are illustrated in Fig. 16-5.

There are only two well made, practical, binocular microscopes designed especially for gem testing, on the market at the present time. The Diamondscope, designed and controlled by the American Gem Society, is made by the American Optical Company. It is a thoroughly good instrument but rather large and awkward in appearance. The instrument

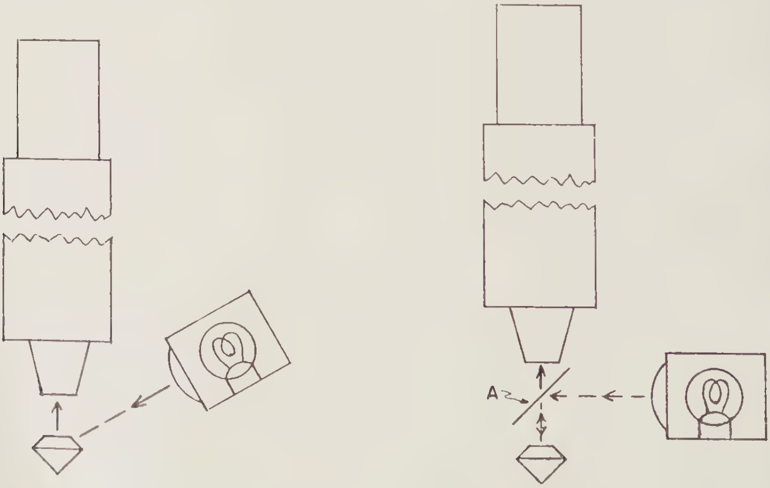


Fig. 16-5. Two methods of top illumination. Left, oblique illumination directly from the light source. Right, complete vertical illumination by the use of a thin transparent glass or "half-mirror." The light from the lamp strikes the mirror at A. Part of it goes through the clear glass and part is reflected directly down onto the object to be viewed. Here it is reflected by the object back toward the mirror. Again, part of the ligh is reflected out toward the lamp and par goes through the mirror and up to and int the microscope. This is inefficient from th standpoint of light loss and requires a goo light source, but it is excellent for viewin when completely vertical light is require This system is used extensively in viewin polished rock and metallurgical specimens

not available to the general public, ut is leased to members of the Ameri- an Gem Society only.

The second and better microscope, the Binocular Gemolite, designed and ld by the Gemological Institute of merica. The optical parts are made Bausch and Lomb.

The De Luxe model Gemolite has eye- eces of 15X, with three objectives ar- nged on a slide for quick changing. ey are .66X, 2X, and 4X. These give e instrument magnifications of 10X, X, and 60X. The instrument provides th dark-field and direct illumination th an iris diaphragm to control the ount of light reaching the stone. It s a well made mechanical stone holder d a pivot base permitting the micro- pe to be turned quickly from one wer to another. The instrument costs out $500.00. See Fig. 16-6.

Just what can be accomplished in the y of gem testing with a loupe or croscope? Very much of this has been swered in the chapters on inclusions d synthetic gems.

With transparent gems it is usually ssible to test quickly for single or uble refraction with the microscope. is also can be done with a loupe if gem is strongly doubly refractive, h as zircon or synthetic rutile.

When viewing a doubly refractive ne through the microscope, in other an a direction of single refraction, me doubling of the back facets will seen. The higher the birefringence, higher the magnification, and the cker the stone, the greater will be visible doubling. Figure 12-20a ows the doubling visible through a con.

If a stone is viewed from a direction ove a facet junction, the line of vision l be divided, and there will be an *pearance* of doubling, even though stone is singly refractive. The stone uld be viewed directly above some et, focused *through* the stone onto opposite surface. It should also al- ys be viewed from more than one ection to avoid the possibility of the t direction being parallel to an optic s and therefore singly refractive.

This doubling, when seen, is quite distinctive. Everything on the opposite side of the stone appears duplicated or paralleled. Whether it is a facet junction, a scratch, or a piece of lint on the surface, it will appear double.

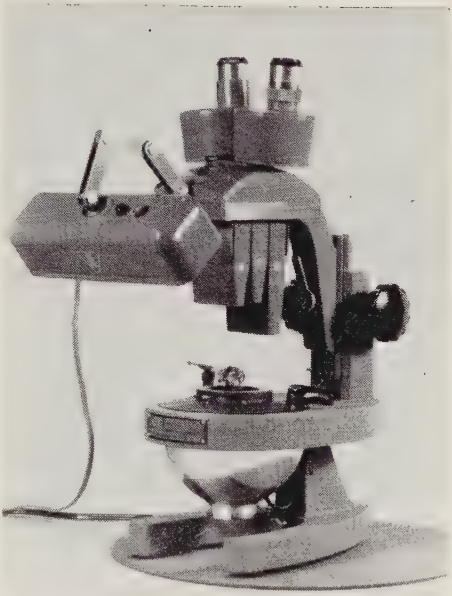


Fig. 16-6. The binocular Gemolite microscope.

If any doubt exists of there being true doubling in a doubly refractive stone, hold a polaroid disc, such as the analyzer from the polariscope, over one eyepiece of the binocular microscope. Rotate the disc back and forth about one-quarter turn. The polaroid cancels one image, and when rotated it cancels the other image. True doubling seen through a doubly refractive stone will appear to jump back and forth as the polaroid is turned. This is positive proof that the stone is doubly refractive, often a big step toward identification.

At times it may be necessary to immerse a stone for proper examination. Doublets, if the parts are particularly well joined, may require immersion to make the plane of junction visible. A small stone of high refractive index may reflect so much light that it will be impossible to view the inside without immersion. Small zircons are often of this nature.

For immersion, any small, flat bottomed vessel, such as a beaker, will be

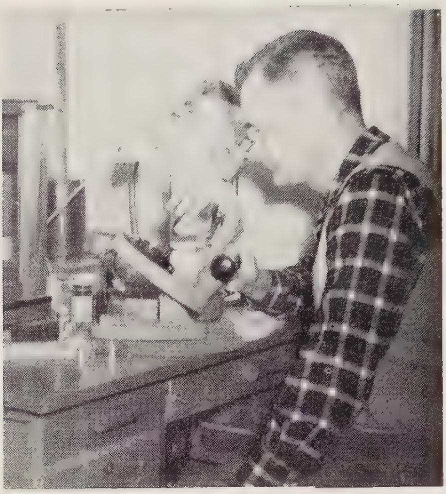


Fig. 16-7. Gemolite microscope in use by Vete George Black, San Diego gemologist.

satisfactory. An immersion fluid with an R.I. near that of the stone is best. The following fluids are suitable:

Liquid	*R.I.*
Water	1.33
Alcohol	1.36
Kerosene	1.43
Turpentine	1.47
Xylene	1.49
Clove oil	1.54
Bromoform	1.59
Acetylene tetrabromide	1.63
Monobromonapthalene	1.66
Methylene iodide	1.74

It is not suggested that all the above liquids be kept on hand. Use the liquid on hand with an R.I. nearest that of the stone. To immerse quartz (R.I. 1.54) any liquid on the list from turpentine to acetylene tetrabromide will be satisfactory. The stone may be placed on the bottom of the glass or held with tweezers in the liquid.

The immersion fluid cuts off light reflections from the surface of the gem and reveals a great deal more detail inside the stone.

When owned by a retail jeweler, microscopes, such as the Binocular Gemolite, are used much more frequently as an aid to diamond sales than as an instrument of gem identification. The average customer, interested in the purchase of an unset diamond, is avid to see the actual imperfections of a stone being considered.

It is always interesting to see the very small difference between an imperfection small enough to cause the stone to be termed VVSI (very very slightly imperfect) and those large enough to be called SI (slightly imperfect). The small difference may rest in the position of the flaw or in its size, but the result is hundreds of dollars difference in the price per carat.

The imposing appearance of these microscopes gives an impression of high power but, actually, 10X is the highest used to show inclusions to a customer. This is quite correct, because inclusions or flaws are *legally* not present if they cannot be seen under 10X magnification. If a diamond shows no imperfections under 10X, it is correctly termed "flawless."

The microscopes described here are those specifically designed for the professional gemologist. There is no doubt that such an instrument is the best, if a person can afford the cost. However, there are many less expensive instruments and adaptions of standard instruments that will allow the amateur to enjoy and use this phase of gemology. Much can be done with less expensive instruments and above all, much fun and knowledge can be gained with them *without* the expenditure of several hundred dollars.

Chapter 17

The Polariscope

One of the most important and useful of gem identification instruments is the polariscope. Primarily used to indicate single or double refraction in transparent minerals and gem stones, it will also show anomalous double refraction in singly refractive gems and will indicate those of cryptocrystalline structure.

It will show dichroism, unless very weak, and the optic character of most transparent stones. Used with the quartz wedge, in most cases it will indicate optic sign.

Lapidaries who cut star stones will find the polariscope very useful in locating the star in mineral fragments.

The modern instrument consists of an enclosed lamp or light source, a fixed polaroid filter above the light, called the *polarizer*, and another polaroid a few inches above the first, which is called the *analyzer*. The analyzer can be rotated.

See Figs. 17-1 to 17-4 for various forms of polariscopes used for gem testing. The folding instrument, Fig. 17-3, requires an external light source. A microscope substage lamp can be used, or it can be held to a convenient window.

Fig. 17-1. New model polariscope by Gemological Institute.

The polariscope is easily constructed by the home mechanic. It consists essentially of a light source and two polaroids. A fine example of a home constructed polariscope, incorporating some personal ideas in design is Fig. 17-2, made by Edward Bohe, F.G.A., San Diego gemologist.

The latest model made by the Gemological Institute of America, Fig. 17-1, costs $21.50. This design is probably the best adapted to gemological use. It also has a window in front to serve as a light source for a refractometer.

The polariscope has certain definite limitations. Being an optical instrument, light must pass through the stone to indicate its type of structure. It is ineffective with the darker translucent to opaque stones. This point should be remembered. *Light must pass through the center of the stone* to give an indication of the stone's structure.

Four Basic Tests

Briefly, here are the four common gem stone reactions in the polariscope.

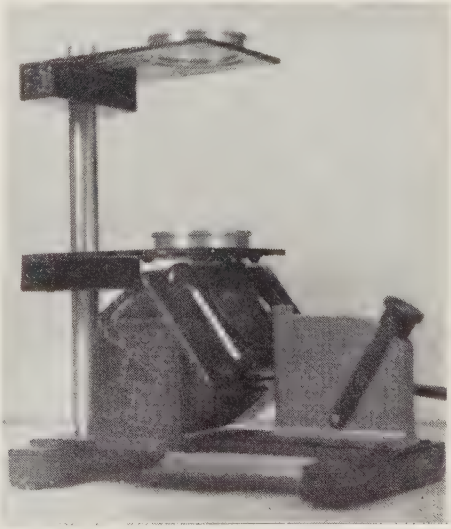


Fig. 17-2. Polariscope made by Ed Bohe, F.G.A., of San Diego. The light source is a microscope substage lamp that turns from the polariscope to the refractometer.

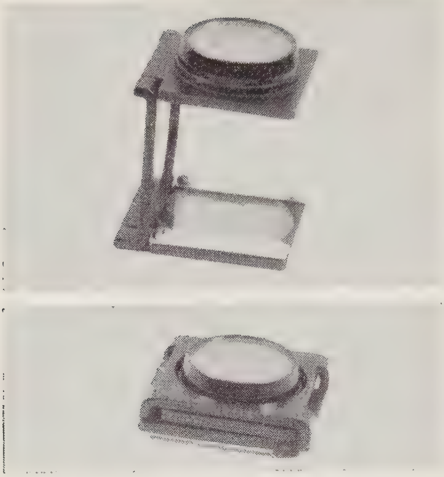


Fig. 17-3. Folding polariscope (made from a folding magnifier).

These will be discussed in more detail later. The stone is held in the fingers or placed in the cup, and rotated in a horizontal plane between *crossed* polaroids. See Fig. 17-4.

1. If it remains dark during rotation, it is singly refractive (abbreviated SR).
2. If it changes from light to dark four times during a revolution, it is doubly refractive (abbreviated DR).
3. If it remains light during rotation, it is cryptocrystalline or a crystalline aggregate.
4. If curved shadows appear to move through the stone as it is rotated, it is anomalously doubly refractive (abbreviated ADR).

There are some variations and exceptions to these four reactions and these will be explained later.

How It Works

To understand the theory of the polariscope, we must understand something about polarized light. In a previous chapter we mentioned that light is of a vibratory nature. Light, as we see it from the sun or another source, vibrates in all directions at right angles to the direction in which it is travelling.

If we looked directly toward a light source and could see the directions in which a single ray of light was vibrating, it would appear something like Fig. 17-5 (with many other rays vibrating in the same manner surrounding it, of course).

If, by any means, we limit the direction of vibration of these many rays to a single direction, we have polarized light. If we could see these vibrations, they would look something like Fig. 17-6. Such light is said to be *plane polarized*.

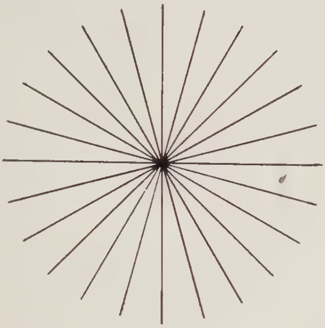
Those of you who performed the feats of imagination required to use imaginary cracker and soap powder boxes in lieu of crystal models will experience no trouble in the use of imaginary Venetian blinds to demonstrate polarized light.

Let us imagine a home with Venetian blinds over the living room windows. The light is turned on in the living room and the blinds are open. The light streams unimpeded across the lawn toward the house of the Jones family next door.

If we now partially close the blinds to a point where only very narrow strips of light can pass, to Jones looking out his window, the effect would be somewhat like that of a polarized light (Fig. 17-6).

Now, suppose Mr. Jones also has Venetian blinds but they are the fancy new type, the ones where the slats run vertically instead of horizontally. In others words, they run at right angles to those in the first house. Now, if Mr. Jones closes his vertical blinds so as to

Fig. 17-4. How a stone is held by hand in the polariscope.



ig. 17-5. Directions of light vibration round a single ray of unpolarized light.

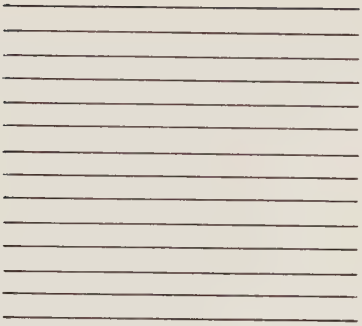


Fig. 17-6. Direction of vibration after polarization.

polarize" the light in a vertical plane, hat coming from the horizontal slits n the first house will not be able to get hrough and very little or no light will e visible to Jones looking through his ertical blinds.

This is what happens when we *cross* he polaroid filters (polarizer and an- lyzer) of the polariscope. Let us say, or example, that the lower polaroid olarizes the light so that after it passes hrough, only that part vibrating in an ast-west direction is left. If we then set he upper polaroid (analyzer) so that it s oriented 90 degrees from the lower, will pass only light vibrating in a orth-south direction. Since the lower olaroid (polarizer) has stopped all the ght that is vibrating in a north-south irection, only that vibrating in an east- est direction can reach the upper polar- id (analyzer). When the light reaches he analyzer it will be stopped alto- ether because only light vibrating in a orth-south direction can go through and there is none, the lower polaroid aving stopped all light vibrating in this irection. The result is darkness (or ear darkness) with the polaroids in hat is termed the *crossed* position.

What Happens

Now, let us see how this dark condi- ion is affected by the presence of arious gem stones between the polar- ids. The sketched schematic diagrams, igs. 17-7 to 17-9, will help to explain his.

If any readers are uncertain about the rms single and double refraction, re- ead Chapter 9. Recall that as a ray of ght enters a DR mineral it is divided into two rays which vibrate at right angles to each other.

Consider Fig. 17-7. The light source is at the bottom. Light coming from this source is vibrating in all directions, at right angles to its direction of propagation (a, Fig. 17-7) until it passes through the polarizer. The polarizer polarizes it and only that part that is vibrating from left to right can get through (b, Fig. 17-7).

Note that a DR mineral has been placed between the polaroids in a diagonal position. Each of the two directions through its structure will pass some light from the polarized beam from the polarizer. The light above the specimen might now be said to be re-polarized in two directions (c, Fig. 17-7). Since the light above the mineral is polarized in two directions, a percentage of light from each ray will pass through the analyzer, making the mineral appear light.

If the mineral is rotated, either to the right or left, less and less light will be transmitted because the mineral will start to act as another polarizer. (Fig. 17-8.) When the mineral is in such a position that one of its planes of polarization is parallel to that of the polarizer, it will transmit the full amount of light delivered to it by the polarizer (a, Fig. 17-8). But this light will be polarized at right angles to the position of the analyzer (b, Fig. 17-8) so no light will go through the analyzer and the field will be dark. There is no light available above the polarizer that is polarized in a plane parallel to the plane of the analyzer, so no light is available that

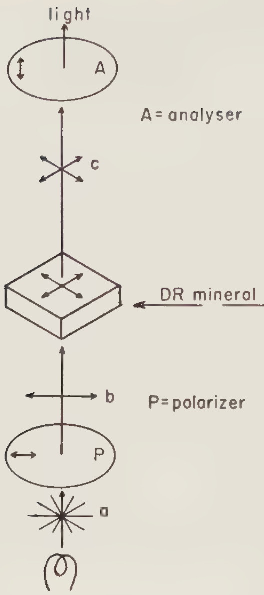


Fig. 17-7. Schematic diagram of polariscope with crossed polaroids; DR mineral in the "light" position.

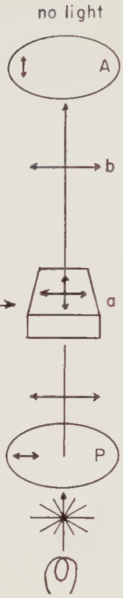


Fig. 17-8. Schematic diagram of polariscope with crossed polaroids; DR mineral in "dark" position.

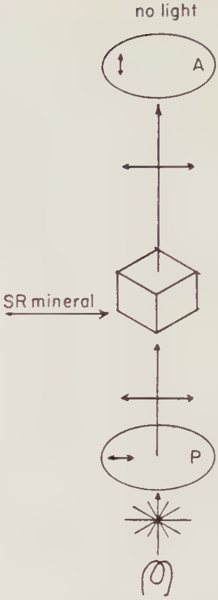


Fig. 17-9. Schematic diagram of polariscope with crossed polaroids; SR mineral between polaroids.

can pass through the anaylzer. The mineral therefore appears dark.

As a DR gem stone is rotated through a full circle between crossed polaroids, it will appear completely light four times and completely dark four times. Fig. 17-10 may help to explain how this occurs. The two large double arrows (a, a) indicate the directions of polarization of the two polaroids in their crossed position in the polariscope. The two arrows in the square (b) indicate the directions of polarization of the light coming through the mineral. In the position illustrated some light from both rays will pass through the top polaroid. If the square is rotated so that the two arrows are parallel to the arrows a-a, there will be no change in the direction of polarization of the light from the polarizer and the analyzer will therefore stop any light that reaches it.

Some persons briefly explain this by saying that a DR mineral "twists" the polarized light until it can pass through the anlyzer.

If an SR mineral such as diamond, garnet, spinel, or fluorite, or amorphous materials, is rotated between the polaroids there is no DR. Fig. 17-9. As polarized light passes through the mineral it will still be polarized in the same direction after it passes. Therefore, there will be no light above the material that can pass through the anlyzer. So, the stone remains dark.

SR minerals or materials may be internally strained and to some extent appear DR. Glass, unless it has been thoroughly annealed after heating, will have internal strains. The polariscope will show curved shadows moving through the material when it is turned.

There are several ways of demonstrating the effect of strained glass. If a fragment of plate glass is gripped by a pair of pliers and held in the polariscope, it will at first appear evenly dark and free of strain. If the pressure from the pliers is increased, lighted areas will appear to surround the pressure point, indicating the area of unequal strain. Or a lighted match can be held under a strain-free fragment of glass. When held in the polariscope, light and dark areas of strain will appear. As the heat is absorbed by the cooler parts of the glass, the strain indications will gradually disappear.

Plastic, if free of strain, will also appear dark in the polariscope. But any bending stress applied will cause lighted areas of uneven strain to appear. Some plastic remains in a strained condition after manufacture. When rotated in the polariscope it will *appear* DR by turning completely light and dark.

Synthetic spinel, manufactured in boule form, always shows ADR to some extent as a result of uneven cooling. See Fig. 12-32. If the stone has been identified as spinel by other means, this fact alone is considered proof of synthetic origin. Natural spinel does not show ADR unless large, visible inclusions are present. In this case, the inclusions will prove the natural origin.

Anomalous Double Refraction

Probably the most confusing simulation of DR is found in almandite garnet. Almandite is SR but because of its metamorphic origin, about 50 to 75 per cent of gem quality almandite is internally strained. ADR in almandite does not take the form of curved, shadowy lines as in strained glass or synthetic spinel. When rotated in the polariscope, true-appearing extinction occurs.

Since ruby of some qualities has a color quite similar to almandite and both may have the same RI and SG, the identity may rest in its SR or DR. Ruby is DR and strongly dichroic. Most gemologists, upon noting apparent DR in a red gem stone, will automatically reach for a dichroscope for the next test. An SR material, no matter how greatly strained, cannot show dichroism. If the material is dichroic, it is ruby. Testing for dichroism will be explained later.

All DR minerals have one or two directions of SR, their optic axes. This was explained in Chapter 9.

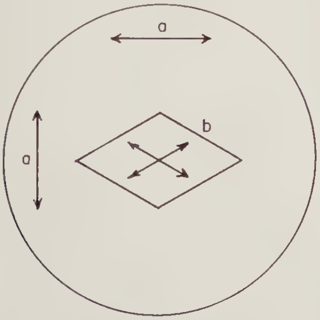


Fig. 17-10. Comparison of polarization directions of crossed polaroids and of a DR mineral in "light" position.

When testing a gem in the polariscope, if at first it appears SR, it must be turned in a different direction at least twice and again rotated before accepting it as truly SR.

Cryptocrystalline Test

In the polariscope, cryptocrystalline minerals such as agate, if thin enough to pass some light, will remain light when rotated. This is also true of crystalline aggregates such as jades, smithsonite, prehnite, etc. But such stones must not be so dense as to prevent some light passing through the *center of the stone.*

There is a reason for this. Many polariscopes have a small cup above the polarizer to hold the stone during rotation. Cabochons, in particular, will receive some light reflected from the sides of the cup. This light will be reflected up to the eye through the analyzer, and as reflected light is polarized to some extent, the result may be a light and dark effect that will make even an opaque stone appear DR through the thin edge of the girdle.

Cryptocrystalline minerals remain light in the polariscope because of their peculiar structure. Agate consists of many very small quartz crystals grouped together at random. In aggregates of quartz or other DR crystals the number of directions in which light will pass when they are in the polariscope greatly exceeds the number of directions in which they will appear dark. Therefore, in a random grouping of crystals there are always a sufficient number of them oriented so they will pass some light.

When testing a transparent or nearly transparent cabochon of glass or some other SR material, the stone may appear like agate, that is, remain light when rotated in the polariscope if the back of the stone is rather coarsely ground. The coarsely ground back appears to upset the passage of light so that some will always be polarized by reflection and pass through the analyzer.

Optic Character

The use of the polariscope to find the optic character (uniaxial or biaxial) of DR gems is both interesting and im-

Fig. 17-11. Holding the glass ball on the end of a glass rod over a specimen to see the optic figure.

portant. The gem must be transparent or nearly so, and not too greatly filled with inclusions.

The optic axis must first be found as it is along this direction only that an optic figure can be seen. The form of the optic figure denotes the optic character. Also, the stone or crystal fragment must not be too thick; possibly about five-eighths of an inch is the limit in thickness. There must be a rounded surface. either on the stone, as on a cabochon. or the rounded surface must be added by some means.

To find the optic axis, hold the stone between crossed polaroids and look for the interference colors that are almost always visible near the optic axis. These are small blotches of mixed colors, somewhat like the colors seen in opal. On a flat surface, one color may cover the entire flat area, hence the necessity of a curved surface. The stone must be turned repeatedly in all directions until a hint of the interference colors is seen. Interference colors are more easily seen in uniaxial stones than in biaxial.

On a curved surface, as on a cabochon or tumbled stone, the interference colors may not appear, but the optic figure may be quickly seen.

The curved surface necessary may be on the stone or it may be introduced above the stone in several easy ways. One of the oldest ways is to hold an eye loupe or other small magnifier above the stone and look for the figure from a distance of 12 to 18 inches above the lens. High magnification is no advantage.

Another method is to place a small drop of one of the heavy liquids used for specific gravity testing, such as bromoform or methylene iodide, on the area where the interference colors are seen. This liquid will form a small lenslike curved surface on the stone. The optic figure seen in the liquid may be small but an eye loupe may be used to enlarge it to easy visibility. In lieu of a drop of heavy liquid, a drop of honey may be found quite satisfactory.

Another and the best of all methods, is to hold a small, clear, glass ball over the interference colors. See Fig. 17-11. The optic figure will be seen clearly *in the glass ball.* A ball of 3/16 to 3/8 of an inch is most satisfactory but perhaps larger ones could be used. Such a ball is sometimes found on the end of the applicator rod in an iodine or other medicine bottle. A photographic stirring rod with a ball end is excellent.

A ball can be formed on the end of a glass rod by heating it in a gas flame, the rod being slowly turned until sufficient glass has melted into a ball on the end of the rod. Be sure to anneal it by cooling as slowly as possible. Even so, there will always be some strain shadows visible when it is held in the polariscope. These shadows do not seriously impair the usefulness of the ball as they tend to disappear when the optic figure is seen.

What They Look Like

To this point we have said a lot about how to find optic figures but nothing about what they look like, and nothing about what they mean. We will try to explain this now.

In the process of elimination which is gem testing, any test that will satisfactorily eliminate a group of gems from the possible list is a good test. The decision as to whether a stone is uniaxial or biaxial is usually a big step toward identification.

Uniaxial gems are those crystallizing in the tetragonal or hexagonal system. Biaxial gems are from the orthorhombic, monoclinic, or triclinic systems. The optic character, that is, whether the gem is uniaxial or biaxial, is indicated by the shape of the optic figure.

The uniaxial figure, Fig. 17-12, is a shadowy cross with a series of concentric, colored circles surrounding the center. Sometimes these colored circles are very tightly grouped around the center of the figure. In other minerals they are more widely spaced. This spacing has to do with the birefringence of the mineral. Those of low birefringence show the more widely spaced circles. The two shadows which form the cross are called *isogyres*.

Another type of optic figure, seen only in quartz, is the circularly polarized uniaxial figure. Fig. 17-13. It is similar to the plain uniaxial figure but with a colored, open center. The color may be almost anything in the spectrum, depending upon the thickness of the stone. If seen, this circularly polarized figure proves the mineral to be quartz, but not all quartz is of the type that shows such figure. Probably not over five per cent of quartz gems will show a plain uniaxial figure.

It has been noticed that plain uniaxial figures are more frequently seen in heat-treated quartz gems than in non-heat-treated stones. We do not know the reason for this. Circular polarization is the result of a peculiarity in the crystal structure and it does not seem possible that heat-treatment could effect such a change. Possibly quartz from certain mines or localities is more frequently heat-treated than others.

The term *uniaxial* indicates a mineral with one optic axis; *biaxial*, a mineral with two optic axes. Chapters 6 and 9 explained this. Figs. 17-14 and 17-15 show the figure as seen in most biaxial gem stones.

The full biaxial figure, Figs. 17-16 and 17-17, may be seen in the polariscope with a glass ball held over a sheet of muscovite mica. The two "eyes" are the centers of the two optic axes which cross in the center of the mineral. This complete figure is seen in only one gem mineral, kornerupine, which has a very low 2V angle. In other biaxial gem minerals only half of the figure is seen at one time in the polariscope. Fig. 17-15.

So we commonly think of uniaxial

Fig. 17-12. Uniaxial optic figure seen in patite (as it looks in the glass ball).

Fig. 17-13. Circularly polarized uniaxial optic figure as usually seen in quartz.

Fig. 17-14. Drawing of optic figure as seen in most biaxial gem minerals.

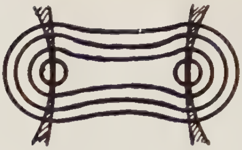


Fig. 17-17. Drawing of a complete biaxial optic figure (also see Fig. 17-20).

figures as having two isogyres forming a cross, Fig. 17-12, and biaxial figures as having a single isogyre curving through the center of the circles. Figs. 17-14 and 17-15.

Another step in elimination which is seldom necessary, but very handy when needed, is the finding of the *optic sign* (+ or —). In addition to the polariscope, a quartz wedge is needed.

How to Use the Quartz Wedge

The use of a quartz wedge in the determination of optic sign (posiitve or negative) in gem minerals is an advanced procedure. It is not often necessary but occasionally a great convenience. Every gemologist should understand its use.

If the stone to be tested has a flat, well polished facet, and medium to high birefringence, it is usually possible to determine optic character and sign with a refractometer. But if the stone lacks flat surfaces or sufficient birefringence it may be impossible. It is then that resort is made to the polariscope and the quartz wedge.

An optic figure must be found in the mineral while it is held between the crossed polaroids of the polariscope as explained above.

Recognizing Optic Sign

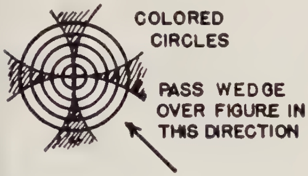
The drawings, Figs. 17-18 to 17-27, will give some idea of how the various optic figures appear in the polariscope. Once the optic figure is found, the quartz wedge usually will determine the optic sign.

It is well to practice finding optic figures in various kinds of gem minerals until it can be done quickly and easily. If possible, keep a few specimens showing each type of optic figure, uniaxial and biaxial, positive and negative.

Hold the wedge horizontally in the polariscope with the polaroids crossed and note that when the wedge is rotated in the plane of the polaroids there are

Fig. 17-15. Actual biaxial optic figure as seen in barite.

Fig. 17-16. Complete biaxial optic figure in muscovite mica as seen through a glass ball.



ig. 17-18.
niaxial

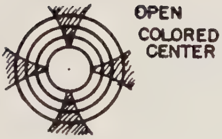


Fig. 17-19.
Circularly polarized uniaxial

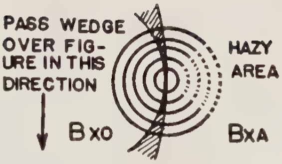


Fig. 17-20.
Biaxial

our positions where no colors are seen n the wedge. Note the positions where he colors are brightest and, when testng a gem showing an optic figure, ass the wedge over it in the brightest osition.

The first practice should be done with stone showing a clear uniaxial optic gure, such as apatite cut as a cabochon ith the optic axis vertically through the pex of the stone. The figure will be niaxial and negative.

When the thin edge of the wedge is assed over the stone it may be seen hat colors, circles, and shadowy brushes isogyres) have bunched together into ur small colored spots, and the figure ow appears like Fig. 17-21. As the edge is passed in farther toward the hick end, the spots appear to be spreadng, and will look something like Fig. 7-22, with two of the spots seeming to pread apart and the other two closing n on each other.

By noting which dots spread when the edge is passed *in* (thin end first), we re able to determine the positive or egative character of the mineral. See igs. 17-22 and 17-23.

When the optic figure is larger there little appearance of dots, but the hole figure divides into quarters as a ie would appear cut into four pieces. s the wedge passes in, two opposing uarters spread, and the two other appear to approach each other. See Figs. 7-24 and 17-25.

Whether the figure under the wedge ppears as four quarters or as dots, the rection of spreading as the wedge asses *in*, indicates the positive or negave character.

The direction of spreading must be oted in relation to the direction of viation of the slow or Z ray, as marked n the cover glass of the wedge. For exmple, if the Z ray vibrates across the idth of the wedge, it will be marked somewhat like Fig. 17-23. If, as the wedge is passed *in* over the *optic* figure, the *spreading* occurs in a direction that will *cross* the Z ray arrow, the sign is positive. Figs. 17-22 and 17-24.

If the spreading occurs in the direction *parallel* to the Z-ray arrow (across the wedge), the sign is negative. See Figs. 17-23 and 17-25. All the above actions are exactly reversed when the

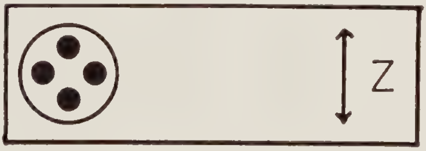


Fig. 17-21.

Fig. 17-22. Uniaxial positive.

Fig. 17-23. Unaxial negative.

Fig. 17-24. Uniaxial positive.

Fig. 17-25. Uniaxial negative.

Fig. 17-26. Biaxial positive.

Fig. 17-27. Biaxial negative.

wedge is pulled out from over the figure.

If the orienting of the quartz has been such that the direction of the Z ray arrow is lengthwise instead of across the wedge, the directions of spreading of the figures will be reversed in relation to the length of the wedge, but *not* in relation to the Z ray arrow. If the spreading occurs in the direction that would *cross* the arrow, the mineral is *positive*. It it is *parallel* to the arrow, it indicates the sign is *negative*.

All the above has referred to the uniaxial figure. It will be found that indications with the quartz wedge over biaxial figures are much more difficult to describe and less distinctive in appearance. It will require more practice to recognize their positive or negative character.

Biaxial minerals have two optic axes, and the optic figure, if seen complete, would appear as in Fig. 17-17. In the polariscope we are seldom able to see more than half the full figure as we can observe only one optic axis at a time. As seen in the polariscope the biaxial figure appears somewhat like that in Fig. 17-14. It is necessary, and sometimes difficult, to determine which side of the visible figure is the side toward the other or invisible half of the figure.

The side of the visible figure that is toward the other half of the whole figure is usually termed Bxa, the side away from the other half, Bxo. If the stone is rotated until the brush or isogyre is parallel to the axial direction of either of the polaroids of the polariscope, the brush will be straight. From this point, if the stone is turned about 45 degrees on a horizontal plane, the isogyre will show a noticeable curvature. The *convex* side of the curve points toward the other half of the biaxial figure (Bxa). Also, the colored circles usually tend to be hazier and less distinct on the Bxa side.

Considering the use of a wedge in which the Z ray arrow is across the width of the wedge, if the wedge is passed in over the figure, parallel to the isogyre, the colored arcs or circles appear to move *toward* the invisible half (Bxa) if the mineral is *positive*. If the circles appear to move *away* from the other half of the figure (Bxo), the mineral is *negative*. See Figs. 17-26 and 17-27. If the wedge is passed over the figure so the wedge is across the isogyre, the reverse of the above is true.

All observations should be made while passing the wedge *in*, starting at the thin end, as all action will be reversed as it is withdrawn.

At first reading, all of the above instructions sound rather complicated and confusing. But this is true only at first trial. It very quickly becomes simple and easy.

A good mineral for biaxial practice is moonstone (orthoclase feldspar) which is biaxial negative. If the specimen is cut en cabochon with one of the optic axes oriented vertically through the apex of the stone, a fine biaxial figure can be seen when it is held in the polariscope. An effort should be made to get practice with both uniaxial and biaxial minerals of known identity so that a faculty for quickly and surely recognizing their positive or negative character is developed.

Chapter 18

The Refractometer

This chapter will explain some of the theory and methods of using the instrument so indispensable to the gemologist —the refractometer. If limited to a single instrument for gem testing, practically all gemologists would select the refractometer as that instrument.

Like all instruments, it has certain limitations. Its scale or useful range of refractive indices is from 1.30 to 1.80. There is no limitation at the lower end as no gem has an index below 1.30. A few imporant gems have an index over 1.80, but this detracts little from the practicality of the instrument.

Other limitations are that the gem tested must have a polished surface, and it must not be a truly opaque species such as pyrite or hematite. Light must penetrate the stone if only for a very short distance. Readings on flat, polished surfaces are the most accurate, but useful readings on rounded and semipolished surfaces can be made.

Several things about a gem can be learned by testing with a refractometer. First in importance, subject to the limitations mentioned, are refractive index and birefringence. Also, evidence or confirmation of single or double refraction is usually found. This is especially valuable when testing gems too nearly opaque to be tested with the polariscope. Optic character and optic sign may be found if the stone has flat, well polished facets and is not too nearly opaque, but it takes careful work.

Refractometers of two makes are available for gemological use. The Gem refractometer, Fig. 18-1, costing about $30.00, is the smallest and the most versatile. It is made and sold by the Gemological Institute of America. The British-made Rayner refractometer, Fig. 18-2, is sold in this country by the G.I.A., and costs about $75.00.

The Gem refractometer is very satisfactory and least expensive. It has a rather small scale which may result in slightly less accurate readings than the larger instrument, but the accuracy and general utility of the Gem refractometer is quite satisfactory. Ninety-nine per cent of our class work and laboratory testing is done with the Gem.

The Gem refractometer, by reason of its simple optical system, is particularly suitable for "spot readings," the only satisfactory method of obtaining refractive indices of very small faceted stones and on curved surfaces of cabochons.

Here, briefly, is the general method of taking refractive index readings with a refractometer. This will be explained in more detail later. A light source is necessary. A microscope substage lamp

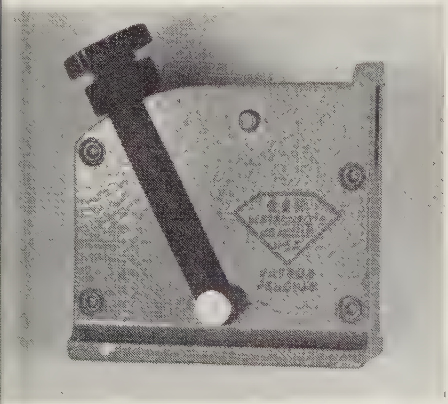


Fig. 18-1. The Gem refractometer.

Fig. 18-2. Rayner refractometer (British).

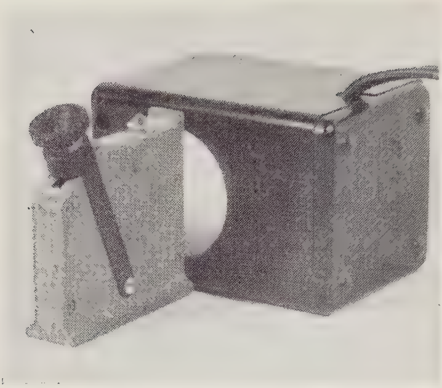


Fig. 18-3. Gem refractometer placed in front of a microscope lamp for illumination. Almost any light source can be used.

is best but daylight through a window can be used. See Fig. 18-3. A small spot of refractometer liquid, about the size of the letter "o" in this print, is placed on the center of the refractometer hemisphere. This liquid is methylene iodide (R.I. 1.74) with the refractive index increased to 1.81 by the addition of sulfur and iodine in the form of tetraiodoethylene.

A clean, flat surface of the stone is placed on the hemisphere, the refractometer liquid excludes the air and completes optical contact with the hemisphere.

The instrument is turned toward the light source and the scale is observed through the eyepiece. If the stone is within the range of the instrument, a partial spectrum of colors, blue, green, and yellow, appears across the scale. The refractive index of the stone is read at the point on the scale where the green of the spectrum blends into the yellow.

When testing faceted stones of 20 points or less, or small facets on larger stones, a spectrum or shadow edge may not be seen. When this occurs, test the stone by "spot method."

In gem identification, refractive index is a most useful property because while it does not always directly identify a gem, when found, it limits the gem's identity to a few possibilities. The refractive index, coupled with other items of data such as birefringence, specific gravity, and appearance, may positively identify the stone.

For a better understanding of the refractometer, it will be necessary to explain something of its construction and theory. Understanding the theory of the instrument will be made easier if the chapters covering optical characteristics are reviewed.

In these chapters you learned that refractive index is the ratio of the speed of light in air to its speed in a denser medium. Although the refractometer scale is calibrated to read in refractive index, it does not directly measure the speed of light, but the degree to which it is bent as it enters the denser substance of the hemisphere. It does this by measuring the critical angle of light in this denser medium as it is affected by the material being tested.

Figure 18-4 shows the construction of the Gem refractometer. Parts 3, 4, 5, and 6 are internal parts.

Critical angle is formed only in the *denser* of two materials in optical contact, when a ray of light leaves the denser material and is refracted into a material less dense. It is the angle with the normal formed by the last ray able to leave the denser material before total reflection takes place. We ordinarily think of a critical angle as the angle formed in a gem stone as light leaves it on entering air. But if the gem stone is in optical contact with a material denser than itself, the critical angle will be formed in the denser material and not in the gem stone. This is what happens in the refractometer. The critical angle formed is the result of a difference in refractive index between the two materials, the gem and the hemisphere, and can be easily calculated by following the equation give in Chapter 8.

The gem stone is placed on the hemisphere and optical contact completed by the small spot of refractometer liquid. Now see Fig. 18-5. Light enters the instrument through the window, passes through the diffusion screen, and strikes the hemisphere. Through the hemisphere it reaches the area of contact between the stone and the hemisphere.

At this point there is a division of light. All rays striking at less than the critical angle, such as ray "a", pass into the stone and out through its facets into

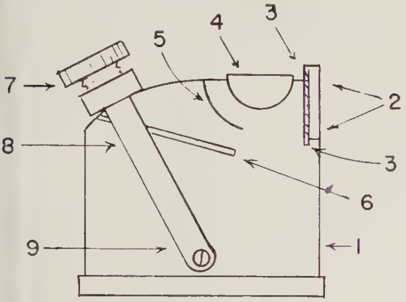


Fig. 18-4. Legend.

1. Body.
2. Window allows light to enter.
3. Diffusion screen.
4. High index glass half-cylinder. Commonly called the "hemisphere" because early instruments were made with an actual hemisphere.
5. Transparent scale. Calibrated to read directly in refractive index from 1.30 to 1.80.
6. First-surface optical mirror.
7. Eyepiece with magnifier, adjusts for focusing.
8. Eyepiece yoke adjusts to eliminate parallax.
9. Yoke tightening screw.

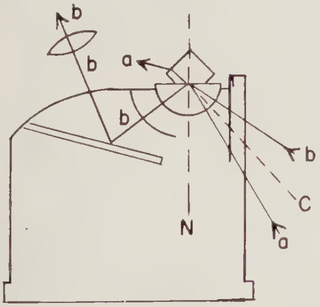


Fig. 18-5

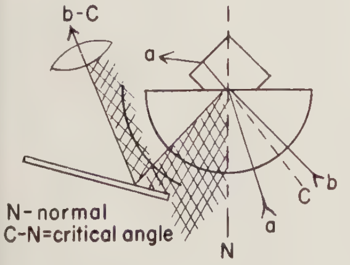


Fig. 18-6

Note: Ray (b) and C (critical angle) are actually coincident but are drawn separated for clarity. All rays above C will be totally reflected to the eye. All rays below C will be refracted into the stone being tested and will pass through the stone to the air. The loss of these rays is what causes the dark section on the scale.

air. Those striking at an angle greater than the critical angle, as does ray "b", are totally reflected within the hemisphere from which they pass through the transparent scale, strike the mirror, and are reflected out through the eyepiece magnifier to the eye.

From the equation given in Chapter 8, it will be seen that gems of differing refractive index placed in contact with the hemisphere will cause different critical angles in the hemisphere. A gem such as almandite (R.I. 1.79) being close to the refractive index of the glass hemisphere (R.I. 1.86) will result in a very large critical angle, and read very high on the scale.

Looking through the eyepiece a dark area will be seen toward the lower numbered end of the scale and a light area toward the higher end, separated by the partial spectrum, indicating the refractive index of the stone.

The dark part of the scale results from the fact that light striking inside the critical angle of the hemisphere is refracted out through the facets of the stone and is not reflected to illuminate the scale. Rays outside the critical angle are totally reflected in the hemisphere and illuminate the higher numbered end of the scale. In Fig. 18-6, follow the paths of rays "a" and "b" through the refractometer.

Although the instrument measures the critical angle in the hemisphere resulting from its contact with the stone, the scale is calibrated to read directly in refractive index. The scale is calibrated in hundredths, each tenth division being numbered 1.3, 1.4, 1.5, etc. With experience, each hundredth may be visually divided into ten parts to give a third decimal place, as 1.655. A drawing of the scale is shown in Fig. 18-7.

Most glass used for jewelry stones probably never exceeds R.I. 1.70, with a hardness of 5½. To make hemisphere glass with a refractive index of 1.86 it is necessary to include a high percentage of lead oxide. This results in a hardness of 4 to 4½ and lessens its resistance to oxidation. Because of the softness, use care in placing a stone on the hemisphere.

Both the hemisphere and the liquid

used to complete optical contact with the stone must be of higher refractive index than the stone tested or no reading will be obtained.

The eyepiece is attached to the instrument by a yoke which is moved forward or back to align the eyepiece with the ray reflected from the mirror which indicates the refractive index of the stone. The drawing of the scale as seen through the eyepiece, Fig. 18-7, shows an outlined blotch which is the reflected image of the contact liquid on the hemisphere. The eyepiece should be moved until the shadowy blotch is horizontally divided by the partial spectrum indicating the refractive index. As the eyepiece is moved, the shadowy outline moves with it, but the refractive index line remains almost steady. The most accurate reading is obtained when the shadowy area, divided by the refractive index line, is about half dark and half light.

When a gem stone over the scale of the refractometer (over 1.80) is tested, the darker shadow seen through the eyepiece will move across the scale and over the 1.80 mark. There will be no appearance of a spectrum. Occasionally, when a stone over the range of the instrument is tested, a series of spectral lines, including some red, may be seen at about 1.80. They may be directly across the scale or at some angle to it. When seen, this partial spectrum is a good indication that the stone is over the scale in refractive index.

When testing an over-the-scale gem, a hazy spectrum line may be seen at about 1.81 on the scale. This is the R.I. of the contact liquid and not necessarily that of the gem.

With any other than an over-the-scale gem, when red is observed on the scale, such as a large irregular area of red, it means that light is entering the system through the gem stone itself instead of through the window and the diffusion screen. This will dim the refractive index line and make readings somewhat inaccurate. It may be eliminated by shielding the stone from any overhead light source with the hand.

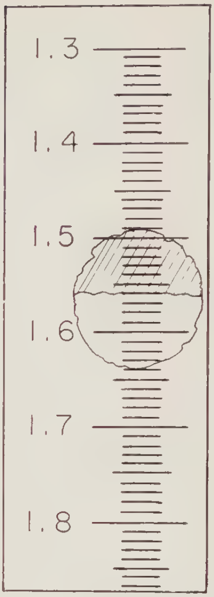


Fig. 18-7

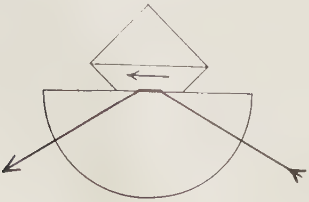


Fig. 18-8

List of common gem stones that may be "over the scale":

Diamond
Zircon
Almandite
Andradite
Spessartite
Synthetic rutile

Less common "over-the-scale" gems:

Sphalerite
Sphene
Strontium titanate
Cassiterite
Scheelite
Wulfenite
Proustite
Zincite

Since all the above gems differ in some property, such as color, specific gravity, or appearance, they are not difficult to separate or identify.

The eyepiece of the refractometer is threaded into the yoke and may be unscrewed to some extent for focusing. Focus on the figures and lines of the scale and the refractive index shadow edge will be seen easily.

For the benefit of those wearing spectacles, it has been found that in most cases the scale is best seen without the glasses. The eye is able to come closer to the eyepiece, giving a wider and clearer field of view.

Birefringence

Equal in importance to obtaining an accurate refractive index reading is obtaining the *birefringence*, or strength of the double refraction. As explained in previous chapter, singly refractive materials have one refractive index and will give only one reading on the refractometer. In doubly refractive minerals, the light upon entering the stone is divided into two rays each with its characteristic refractive index. The difference between these two indices is the birefringence.

It will be understood by those who have read and reviewed Chapter 9 that these two rays passing through the doubly refractive mineral vibrate in directions at right angles to each other. They are, therefore, differently absorbed or slowed down by their passage through the crystal. Traveling at different speeds, each will have a different index.

It must be understood that light passing from the hemisphere and a very short distance into the material in contact with it, does to some extent, optically analyze the structure of the material. The structure of the stone is analyzed by the action of the light that passes through it in a direction parallel to the surface and the long direction of the hemisphere. This direction is indicated by a small arrow in Fig. 18-8. If this is a direction of single refraction in the stone, only one refractive index will be seen on the scale. If the stone is given a quarter-turn on the hemisphere, double refraction will be indicated and two readings seen.

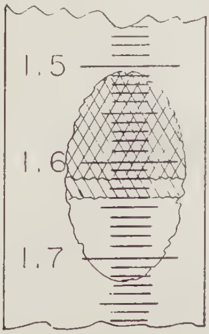


Fig. 18-9

There are two types of doubly refractive stones, uniaxial and biaxial. We will consider uniaxial first. Uniaxial minerals have only one direction of single refraction (parallel to the *c* axis). If this direction of single refraction in a gem stone is placed parallel to the long dimension of the hemisphere, the stone will appear singly refractive and only one refractive index reading will be found. If it is rotated until its direction of single refraction is at right angles to the hemisphere, it will be doubly refractive and maximum birefringence will be indicated. Placed at other angles between the two, proportionate amounts of birefringence will be found. Figure 18-9 shows how this will appear on the scale.

Use of Polaroid Plate

It is not always possible to see both shadow edges of a doubly refractive mineral. Some persons are never able to see them both at once. Since the two rays causing the two readings are vibrating in directions at right angles to each other, a polaroid filter held over the eyepiece, will effectively obscure either of the two rays from view. A special polaroid eyepiece cap is available for all refractometers or the top polaroid from a polariscope may be used. When held over the eyepiece of the refractometer, the polaroid will pass light vibrating in one direction only and only one refractive index will be seen. When turned 90 degrees, it will pass light vibrating at right angles to the first and the other refractive index will be seen. It is often possible to read both refractive indices of rather weakly birefringent gems by turning the polaroid back and forth about a quarter-turn, causing the shadow edge to jump quickly from one reading to another.

Whether two shadow edges are seen at the same time or with the help of the polaroid, they are definite proof of double refraction. But a single line cannot be considered proof of single refraction.

In Fig. 18-10 the top row of sketches shows the positions in which a rectangular tourmaline gem could be placed on the refractometer hemisphere. The arrow indicates the direction of single

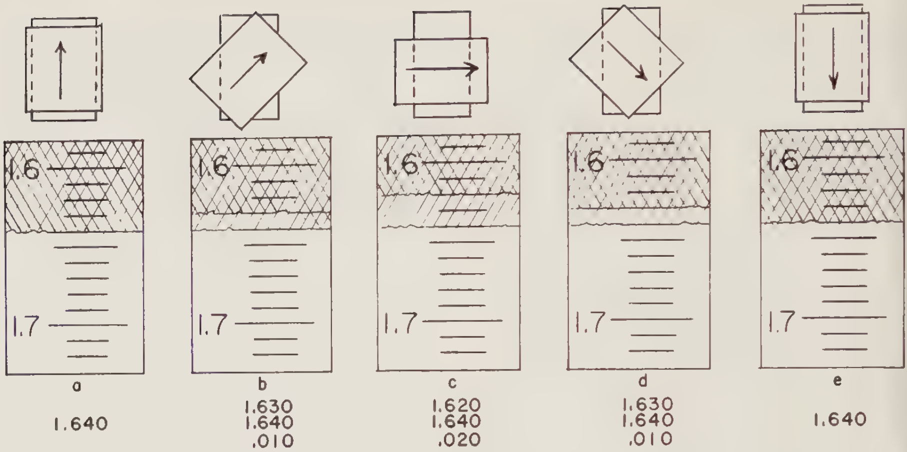


Fig. 18-10

refraction in the gem. Below these are illustrated sections of the refractometer scale showing the readings that would result from the positions of the gem above. These are marked (a) to (e). Below each sketch are the actual figures from the shadow edge positions. Diagrams (a) and (e) show a single refractive index, 1.64, since the stone is in a position of single refraction. The lines in (b) and (d), 1.63-1.64, show one-half the maximum birefringence because the stone is at an angle of 45 degrees, halfway between zero and maximum birefringence. At (c), 1.62-1.64 is shown as the stone is in the position of maximum birefringence of which the mineral is capable.

Below (b), (c), and (d), the bottom figures are the amounts of birefringence. These are the differences between the lower and higher readings.

Other Useful Information

Other useful facts may be learned from the above data. In Fig. 18-10, note that in all positions of the stone, the figure 1.64 remains constant. This indicates a uniaxial mineral. As the mineral is turned to successive positions, *if only one shadow edge moves, the mineral is uniaxial. If both shadow edges move to some degree, the mineral is biaxial.* Whether a mineral is singly refractive, uniaxial, or biaxial, is termed its *optic character*.

Another fact, sometimes very useful, is the *optic sign* of a mineral. Whether it is optically positive (+), or negative (—). As in Fig. 18-10, if the lower refractive index number moves it is negative. If the higher refractive index number moves it is positive. Perhaps it can be expressed more concisely. If the *lower number only*, moves, it is *uniaxial negative.* It the *higher number only* moves, it is *uniaxial positive.* If both numbers move but the lower moves the most, it is *biaxial negative.* If both numbers move, but the higher number moves the most, it is *biaxial positive.*

Any facet on a uniaxial stone, when rotated on the refractometer hemisphere, will, at some point, give readings for maximum birefringence. If a crystal of tourmaline (uniaxial), polished on one side and on one end, is placed polished side down on the hemisphere, it will show maximum birefringence if at right angles to the hemisphere, and zero birefringence or single refraction if lengthwise to the hemisphere. If placed on the hemisphere end down, no matter how it may be turned, it will show maximum birefringence. With the end of the crystal on the hemisphere it would be impossible to take readings to show optic sign.

With biaxial gem stones it is often more difficult to obtain an accurate set of readings that will give maximum birefringence and optic sign. Biaxial minerals have two optic axes. These are the two directions of single refraction. Due to this peculiarity of crystal structure, it may be impossible to obtain refractive index readings giving maximum bireringence and useful readings for optic gn on facets oriented in certain direc-ons. When testing biaxial stones it is onsidered advisable to take readings on t least two facets, if possible.

Before writing this chapter, we care-ully tested five stones of peridot, a iaxial mineral of high birefringence. e were unable to get useful readings n the back facets so all tests were made n the table facets. All gave readings atisfactorily close to normal birefringence (.038), but only two gave reliable ndications of their optic sign.

There are greater complications when esting biaxial stones for maximum birefringence and optic sign. The stone is laced on the hemisphere, a polaroid late is rotated over the eyepiece, two efractive index readings are seen and ritten down on scratch paper. The one is rotated about one-eighth turn n the hemisphere and another pair of eadings taken. This is repeated four six times until the stone has been rned at least 180 degrees, after which e numbers must be carefully evaluated. ere are six pairs of refractive index eadings taken from one of the peridot ems tested:

688 1.680 1.688 1.682 1.668 1.668
670 1.670 1.668 1.668 1.656 1.650

elect the highest number in the upper w and subtract from it the lowest umber in the bottom row:

$$\begin{array}{r} 1.688 \\ -1.650 \\ \hline .038 \end{array}$$

ne remainder, .038, is the birefringence the stone. Next, select the highest umber in the upper row and subtract om it the lowest number in the same w:

$$\begin{array}{r} 1.688 \\ -1.668 \\ \hline .020 \end{array}$$

o the same with the bottom row, subact the lowest from the highest numr:

$$\begin{array}{r} 1.670 \\ -1.650 \\ \hline .020 \end{array}$$

The rule is that *if the upper row shows e greatest amount of variation, the ineral is positive. If the bottom row varies the most, it is negative.* According to the above results both are the same, so the mineral is neither positive nor negative. This is the usual condition for peridot.

Let us check the results from another peridot gem the table of which was cut at some other crystallographic angle:

1.680 1.682 1.682 1.682 1.685 1.685
1.650 1.648 1.658 1.662 1.650 1.662

Subtract the lowest number from the highest number in the top row:

$$\begin{array}{r} 1.685 \\ -1.648 \\ \hline .037 \end{array}$$

This gives an acceptable birefringence, not quite as accurate as that of the first stone, but useful.

Subtract the lowest from the highest number in the upper row:

$$\begin{array}{r} 1.685 \\ -1.680 \\ \hline .005 \end{array}$$

The same for the bottom row:

$$\begin{array}{r} 1.662 \\ -1.648 \\ \hline .014 \end{array}$$

As mentioned, the row showing the greatest variation indicates the optic sign, *providing it varies more than half the birefringence.*

The birefringence of the stone is .037, one-half is .0185. The top row varies .005, the bottom varies .014. Neither is more than half the birefringence, so these readings will not indicate the optic sign acceptably. In such cases a second set of readings, if obtainable from another facet, usually will give the optic sign.

Monochromatic Light

The refractive index of a mineral, as obtained through the use of a refractometer, will vary with the wave length (color) of the light used for observation. Commonly, white light is used, giving a rather broad line in the form of a colored partial spectrum. The refractometer is calibrated for light waves around the middle of the visible spectrum, that is, yellow light (5890 angstrom units). The yellow part of the spectrum seen on the scale of the refractometer is often less visible than the blue and green. So it is at the lower edge of the green, where it blends into the yellow, that the refractive index is taken.

If red light of about 6500 A.U. is used to illuminate the refractometer, the reading will be about one-half scale division (.005) higher than that of yellow light. If violet light (4000 A.U.) is used, the reading will be one scale division lower than yellow light. Approximations of these wave lengths can be obtained by the use of colored filters.

A source of pure yellow light is often used to illuminate the refractometer. This is called a monochromatic light source. The lamp in this unit is a type NA-1 sodium vapor lamp made by General Electric Company. The light generated is very close to the 5890 A.U. of pure yellow light. The unit is made and sold by the Gemological Institute of America and costs about $80.00.

The advantage of such a light source is that because only one wave length of light is supplied, there can be no spectrum of colors on the scale. Instead. there is a sharp shadow edge, giving greater accuracy in readings. With a well polished gem surface, it is comparatively easy to obtain refractive index readings to the third decimal place. Accurate birefringence readings and readings for optic character and sign should be made, when possible, with a sodium vapor light source.

With white light, useful birefringence readings down to about .010 can be made. Below this, one sees the line move and guesses. With a sodium vapor light, a clean hemisphere, and experience, the gemologist should be able to obtain birefringence readings down to .005 with fair accuracy. Of course, refractometers with larger scales, such as British Rayner, make accurate readings easier to obtain.

There is a second model of the Rayner refractometer which we have neglected to mention. It is called the Spinel Model because the hemisphere, or in the Rayner instrument a prism, is made of synthetic spinel. Eight in hardness, it is vastly more difficult to scratch than the soft glass used in other refractometers. The instrument has a slightly more elongated scale and when used with white light does not show a colored spectrum but a shadow edge much like other refractometers when used with a monochromatic light. The one disadvantage, and it is a big one, is that the top limit of the scale is 1.66. Therefore, it cannot be used for testing gem minerals wtih an R.I. of over 1.66. Many minerals are in this group.

In general, when using the refractometer, it will be found that gems of high dispersion show a sharper refractive index line than those of low dispersion. This is not very noticeable, because all gems of very high dispersion, such as sphene, sphalerite, synthetic rutile, and strontium titanate. are over the scale of the refractometer.

In an emergency, a jury-rigged sodium vapor light can be improvised by putting table salt around the wick of a candle. Or if more brilliance is needed, saturate an asbestos string in a strong salt solution and suspend it in the flame of a Bunsen burner.

The advantages of a sodium vapor lamp are many. Accurate readings not otherwise possible, result from its use. One of the disadvantages is that a very well polished, flat surface is necessary to get a sharp shadow edge, or even a usefully visible line. If, after the stone has been placed on the hemisphere of the refractometer, a clearly visible spectrum line cannot be seen with white light, it will probably be impossible to see any line at all with the monochromatic light.

Spot Readings On Curved Surfaces

So far we have only explained the use of a refractometer with gems having flat surfaces. It is also possible and practical to take refractive index readings from curved surfaces such as cabochons with no flat polished back, small carved objects, small spheres, etc. The method used, commonly called the *spot method*, was discovered and developed by Lester Benson and Robert Crowningshield, of the Gemological Institute of America. Very accurate readings and birefringence seldom can be obtained by the spot method, but it will give useful information practically unobtainable in any other way.

It is especially useful when testing a

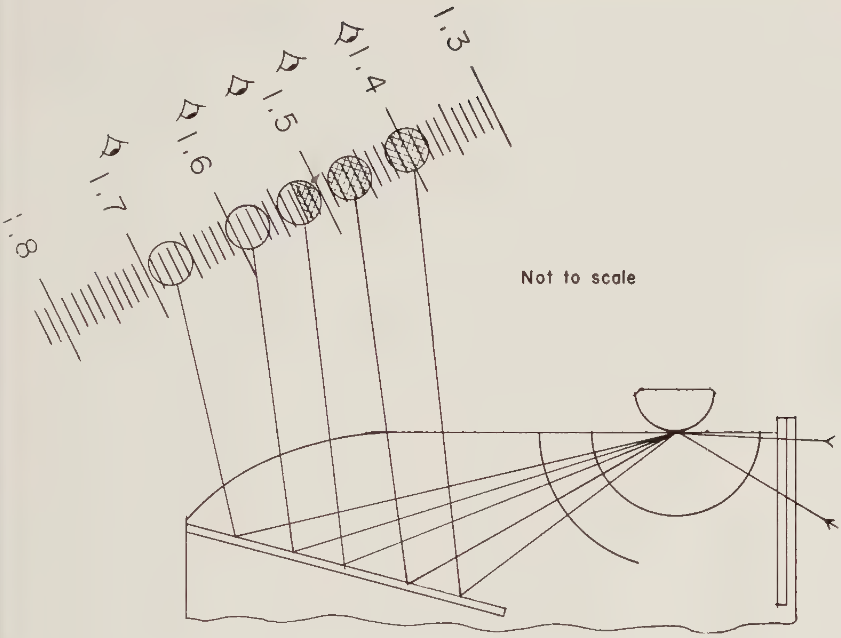


Fig. 18-11

mall carving or figurine of jade, to stablish its identity as nephrite or adeite, which may differ widely in alue. It is useful also on very small ones or small facets of larger stones. ometimes a useful R.I. can be obtained om rough gem materials, such as crys- ll faces, a cleavage surface, or a oughly polished protrusion on a worn ecimen. But in all such tests, ex- rcise every possible care not to scratch e hemisphere of the instrument.

The surface tested must be polished some extent. The higher the polish, e more accurate the indication.

We will explain the testing of a small bochon with a rough back on which reading can be obtained.

Place a very small spot of refractom- er fluid on the center of the hemi- here. By small, we mean something out the diameter of the body of a mmon pin. Place the rounded top of e cabochon in the spot of liquid. If e stone is a double cabochon, it is tter to test the surface with the higher rvature rather than the flatter back.

The eyepiece of the refractometer must lowered from its usual place over the irror, as it is not used for the test. he eye of the observer must be close to the top of the refractometer, at a distance at which the numbers of the scale can be seen reflected in the mirror. Move the eye forward and back, higher or lower, until the black spot caused by the stone and liquid is seen.

At this point, move the head toward the rear of the instrument, watching the spot until it appears to turn light and becomes merely a dark ring around the light spot. Moving the head back and forward, it will be noted that at some point the spot will appear half light and half dark. This is the point where the refractive index is read from the numbers on the scale. Practice with gems of known R.I.

Figure 18-11 is a schematic drawing of the refractometer, the light rays, and the appearance of the spot as seen on the scale. It is dark at the lower numbered end, light at the higher numbered end, half dark, half light at the point on the scale indicating the refractive index.

Do not be concerned with which half of the spot is dark at the R.I. point. It may be either, according to the curvature of the stone tested. Small cabochons usually show the higher numbered half remaining dark. Large, or almost flat cabochons, and very small facets cause the lower numbered half to remain dark.

If, as the head is moved, the spot does not seem to divide, half light and half dark, but only fades out toward the higher end of the scale, note the last point at which the spot is all dark, then the first point at which it is all light. Halfway between these points on the scale is an approximation of the R.I.

On some cabochons and some small facets, a hazy green line may be seen bisecting the spot. This gives a good refractive index reading.

When first viewing the spot as reflected by the mirror, be sure it does not cover more than three divisions on the scale. A large spot makes a very uncertain reading. To reduce the size of the spot of liquid on the hemisphere, touch the stone to be tested to the spot, lift it, and wipe the hemisphere clean with tissue. Replace the stone on the hemisphere and it will be found that sufficient liquid was picked up by the stone to complete the test.

Some persons may not be able to see the small figures on the refractometer scale with the naked eye. A binocular or single eye loupe may be used, hand held, or attached to the head. Use just sufficient magnification to permit reading the scale and the spot will be seen easily.

Occasionally, small cabochons may be encountered that do not give satisfactory spot readings due to poor polish, lacquer on the surface, etc. On such stones the appearance of the spot, as seen in the mirror, is distinctive. The spot as seen at either end of the scale will have a light center with a rather heavy black border. Moving the head backward and forward changes the appearance of the spot very little, so there is no definite place to take a reading. When this condition is encountered, try a different part of the stone for testing, or rub the surface briskly on cloth or paper before testing.

When testing by the spot method, the stone or carving does not have to lie of its own accord on the hemisphere. It may be held in the fingers and touched lightly to the hemisphere while a reading is taken. This is particularly convenient when testing carved figurines that are too large to place or balance on the hemisphere. A well polished surface of some rounded protruding portion may be touched to the small spot of liquid on the hemisphere for a quick reading. Be sure no sharp corner touches the hemisphere.

So far, we have discussed the use of the Gem refractometer only for spot method refractive index readings. The Rayner refractometer seems much less suitable for spot readings. We have two of these instruments, both the spinel and regular model, but have never succeeded in finding a method for reliable spot readings. British gemologists seem to have no difficulty with the instrument and curved surfaces. The reason we have not learned is probably because we have the simpler Gem refractometer always at hand, reserving the more accurate British instrument for use with flat surfaces where more careful analysis is required.

For those who have Rayner refractometers, spot readings can be taken by removing the eyepiece, or looking through it from a distance of 18 inches or more, then gradually lowering the eye until the scale numbers can be read. It takes practice.

Monochromatic light is never used for spot readings.

Care and Cleaning

Any refractometer is a delicate instrument and must be accorded reasonable care. The hemisphere should be wiped after each index is obtained. Lens tissue is the best but ordinary tissue, such as Kleenex, is satisfactory. If the refractometer liquid is forgotten and allowed to dry on the hemisphere, wipe off and clean the hemisphere with a tuft of tissue dipped in xylene.

The highly leaded, soft glass hemisphere will oxidize or tarnish after considerable use or some neglect. When this occurs, it will be noticed that when the spot of liquid is placed on the hemisphere, it tends to roll off the side and spread over the top of the instrument instead of remaining where placed. It may also be noticed that readings are somewhat less distinct. When this condition occurs, wash the hands carefully, eaving one finger tip slightly wet. Touch that finger to a little cerium oxide and rub gently back and forth over the hemisphere for about 30 to 60 seconds. Use very little powder and do not let it enter the instrument. Clean the instrument carefully and wash the hemisphere with xylene.

The mirror is of the top or first surface type and is very susceptible to scratches. On the older model Gem refractometers without a plastic cover over the mirror, clean the mirror carefully with a small *soft brush only. Do not use tissue.*

In spite of due care, scratches will occasionally occur on the hemisphere of the instrument. If it can be avoided, never test diamonds on the refractometer. Almost certain — one test, one scratch. A few small scratches do not ruin the instrument. If they become quite noticeable on either the hemisphere or the mirror, the instrument should be returned to the G.I.A. for repair. They offer a fine repair service, which includes replacement of the hemisphere and mirror, cleaning and recalibrating at a nominal charge.

Comment

Many persons interested in gemology at first fail to understand the difference between birefringence and refractive index *range.* Both may be found in most data tables. Due to slightly varying chemical composition and other factors, the refractive index of all minerals varies to some extent. This is called the *range.* Birefringence is the strength of the double refraction, and is much more constant. For example, if the higher reading of a stone is found to be little higher than normal, it is most probable that the lower reading will be approximately the same amount higher, leaving the birefringence normal. Occasionally we find a mineral with variable birefringence, such as andalusite, which may vary from .009 to .013, and epidote, from .030 to .040.

One thing must be kept in mind about biaxial stones. Although accustomed to thinking of both the higher and lower refractive indices changing as the stone rotated and successive readings are taken, wtih a few minerals the variation of one or the other index is so slight as to be almost imperceptible on the refractometer. One of these is augelite. The lower R.I. will move from 1.576 to 1.574, a difference of only .002. The higher index moves from 1.576 to 1.588, a difference of .012, and the stone may easily appear to be uniaxial. Barite is another of this type with a lower index from 1.637 to 1.636 and a higher index from 1.637 to 1.648.

In such cases other properties and data must be used to complete positive identification. In gem testing, it is seldom, indeed, that a single property or a single test can be relied upon for positive identification.

Other Refractive Index Methods

The Becke method of R.I. measurement is used frequently in mineralogy, only occasionally is it useful in gemology. It consists of comparing the R.I. of mineral fragments or a cut gem with that of a liquid of known R.I. when they are in contact.

If mineral fragments, immersed in a liquid of known R.I., are observed through a microscope with the light adjusted properly, a frame of light will outline each fragment. As the microscope objective is *raised* the light appears to move *into* the material, mineral or liquid, of *higher* R.I. If the objective is lowered, the light will move into the material of lower index. The greater the difference in R.I. between the mineral and the liquid, the more active the movement of the light ring, yet rather small differences in R.I. can be seen.

If it is found necessary to use the Becke method on a cut stone, the stone can be mounted, table up, with wax on a microscope slide and a small drop of the proper liquid placed on the stone. The light frame will surround the drop of liquid and appear to move as described for immersed mineral fragments.

Some adjustment of the substage diaphragm and light souurce may be necessary to create the light ring.

Refractive index liquids such as water 1.33, turpentine 1.47, xylene 1.49, clove oil 1.54, bromoform 1.59, acetylene tetrabromide 1.63, methylene iodide 1.74, and refractometer fluid 1.81 may be used.

Duc de Chaulnes Method

Another method seldom used but occasionally valuable for minerals or gems with an index higher than can be read on the refractometer is the method of the Duc de Chaulnes. It is a method of direct measurement of real and apparent depth of the gem, through the microscope.

A microscope with a calibrated fine adjustment must be used. The gem, with table up and horizontal, is waxed to a slide. The instrument is carefully focused on the table surface of the gem and a note made of the fine adjustment reading. The objective should then be *lowered by using the fine adjustment screw only* until it is focused on the bottom or culet of the stone and another reading taken. The difference between the two readings will be the *apparent depth* of the stone.

The instrument is again focused on the table surface and a reading taken, after which the slide and stone are moved aside slightly. Still using the fine adjustment only, focus on the top surface of the slide upon which the stone rests but without the stone intervening. Another reading is taken and the difference between the last two will be the real depth of the stone.

$$\frac{\text{Real depth}}{\text{Apparent depth}} = \text{R.I.}$$

When using a microscope for this test, the backlash inherent in most instruments must be taken up by turning the fine adjustment screw in one direction only when changing from a focus on the table to a lower point. That is, focus on the table while lowering the objective. Note the reading, then continue focusing down to an exact focus on the lower point. If necessary to reverse the direction at any point, start over again.

Even with this precaution the method is incapable of great accuracy.

R.I. Ranges

When referring to tables of gem stone characteristics, the R.I. figures are frequently preceded by the letters O and E or X, Y, and Z. These indicate the R.I. of the various axes of the mineral.

Singly refractive minerals have one refractive index. Uniaxial minerals have two refractive indices, one for the ordinary and one for the extraordinary ray. The letter E represents the index of the extraordinary ray. The letter O represents the index of the ordinary ray. If the E index is larger, the mineral is positive. If the O index is the larger, the mineral is negative. In some texts the Greek letters omega and epsilon are used in lieu of these letters.

Biaxial minerals have three refractive indices. We use the letters X, Y, Z, to represent these rays. Somewhat more common is the use of the Greek letters alpha, beta, and gamma for the same purpose. Two of the best mineralogical authorities differ on this. Dana's books use the Greek letters. Winchell prefers to use X, Y, Z, as do we, to avoid any use of Greek letters in lessons of this kind.

These letters represent different refractive indices which are the result of different *light velocities* through the crystal. As light enters a doubly refractive mineral, it is polarized into two rays, O and E, or X and Y, which vibrate in directions at right angles to each other. If the mineral is biaxial, light may enter from another direction and be polarized to vibrate in the directions Y and Z.

Uniaxial minerals have only two possible directions of vibration and therefore two different refractive indices. Biaxial minerals have three possible directions of vibration, three possible different speeds of light, and three refractive indices. X always represents the lowest R.I., Y represents the intermediate, and Z the highest R.I.

If the difference between the X and Y is greater than the difference between Y and Z indices, the mineral is negative. If the difference between the higher index Z and the intermediate Y is greater than between X and Y, the mineral is positive.

Note that in all tables the difference between X and Z, or O and E, the highest and the lowest index, is the *birefringence* of the mineral.

Identification of Red Garnets

Almandite, rhodolite, and pyrope, the red garnets, are not always easy to separate. Specific gravity cannot be used because they overlap in this characteristic. They should be separated on the basis of refractive index and color.

The R.I. range of almandite is from 1.76 to 1.83. The range of pyrope is 1.74 to 1.76. Rhodolite ranges from 1.75 to 1.77. Separation might be easy except for the fact that at 1.76, the garnet might be any of the three.

At R.I. 1.76 the color will spell the differences. Rhodolite is the most distinctively colored with its violetish-red. *It must be violetish-red* to be considered rhodolite.

Almandite range, 1.76-1.83	**1.83**	
	1.78	**- Normal R.I. of Almandite**
	1.77	**Rhodolite range, 1.75-1.77** **(Color must be violetish red)**
	1.76	
Pyrope range, 1.74-1.76	**1.75**	
	1.74	

The better grades of almandite are purplish red in color but most stones appear more nearly brownish red. Pyrope is brownish red but almost invariably of a more intense, more vivid color than almandite.

The spectroscope readily separates almandite and pyrope, each having distinctive absorption bands, but in the spectroscope, rhodolite appears the same as almandite even thought it is composed of approximately two parts pyrope and one part almandite. Of course, to separate rhodolite, one can always do as is most commonly done in the jewelry trade. If it looks like rhodolite—sell it for rhodolite.

Small Gem Stones

Most students of gemology have difficulty when they first encounter stones of 1 to 5 points. Such stones are hard to handle and if dropped are almost invariably lost. When handling with tweezers, always keep the other hand under the stone as it is moved about.

Refractive index can be obtained by the spot method. Occasionally a spectrum line may be seen as with a larger flat surface.

More difficult is the problem of single or double refraction in the polariscope. Light reflects from the small facets and singly refractive or doubly refractive small stones may appear very much the same when they are rotated between polaroids. This can be overcome by dropping the stone in any bottle of heavy liquid in which it will sink. The bottle cover is left off and the whole bottle rotated between the crossed polaroids. The liquid stops reflection of light from the small facets and extinction of light through the stone, if present, will be clearly visible.

Chapter 19

Specific Gravity Methods

To a gemologist, specific gravity (abbreviated S.G.) is the relative density of a substance compared with a standard. The standard is water. The two common methods of finding the S.G. of a gem, the hydrostatic and the heavy liquids methods, have been explained in theory. We will now explain their practical use.

The hydrostatic method using a diamond balance (or some other accurate scale) is simple. A length of light stainless steel wire, with a hook on one end to hang from the left pan support, the lower end formed into a helical basket, is used to support the stone. Another wire of exactly the same length as the first, to be coiled in any convenient manner, is hung on the right-hand pan support hook to act as counterweight for the first wire.

A small glass beaker or jar to hold the water is necessary. A 50 or 60 ml (milliliter) beaker is fine. We use a small mayonnaise jar with the top cut off on a lapidary trim saw. Dimensions about 1¾ inches wide and 2¼ inches high are about right.

A support bracket for the beaker can be made from light sheet aluminum. A flat bottomed, inverted U-shape works very well. We use a U bracket, laid on its side, to set under and over the left-hand pan of the balance. See Figs. 19-1, 19-2 and 19-3.

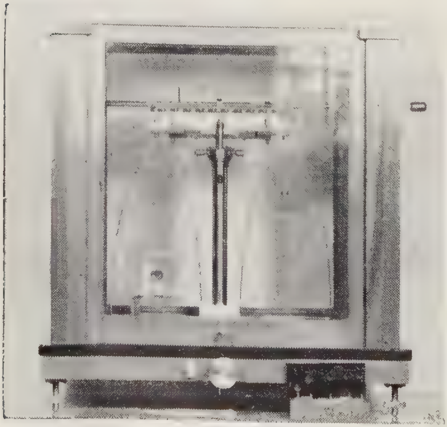


Fig. 19-1. A diamond balance fitted for specific gravity testing.

The bracket must be high enough to support the beaker above the highest position of the pan and be positioned so it will never touch the pan as it moves up and down. The pictures show the arrangement of the wire, beaker, and bracket.

Before using, the equipment must be checked and carefully balanced. Fill the beaker with water and hang both wires on their hooks above the pans. The wire basket should be well under the water, deep enough to support a stone ¾ to 1 inch under the water's surface.

File or cut off the counterbalance wire until the two wires balance perfectly with the stone support wire *in the water.*

How to Weigh

Weigh the stone in air by placing it on the pan under the beaker support bracket. Let us say it weighs 12 carats in the air.

Remove the stone from the pan. Unhook the basket wire and remove it from the water. Place the stone in the basket and replace the wire on its hook with the stone hanging in the water. Be sure it is well covered and does not touch the sides of the glass beaker.

Weigh it carefully. Let us say it weighs 9 carats.

Find the difference between the weight in air and the weight in water by subtracting 9 from 12, which leaves 3 carats This is the weight of the water displaced by the stone.

Divide the weight of the stone in air by the weight of the water displaced: 12 divided by 3 equals 4.0, which is the specific gravity of the stone.

$$\frac{Wa}{Wa - Ww} = S.\,G.$$

Where:
Wa is weight in air
Ww is weight in water

Other Liquids

Water has a rather high surface tension. In past years it was common practice to weigh the stone in a liquid of low surface tension instead of water. Carbon tetrachloride was often used when testing stones of a carat or less. Any liquid can be used if its S.G. is known. The S.G. of the liquid is used as a correction factor (CF) with which to multiply the first answer.

The S.G. of carbon tetrachloride is 1.59. If the 12 carat stone, mentioned above, had been weighed in carbon tetrachloride instead of water it would work out as follows:

Weight of stone in air, 12 carats. (Wa)
Weight in carbon tetrachloride, 7.23 carats. (Wl)
12 minus 7.23 equals 4.77 (the weight of the carbon tetrachloride displaced).
12 divided by 4.77 equals 2.51.
2.51 times 1.59 (CF) equals 3.99+ (the S.G. of the stone, as close as we can get using only two decimal places.)

The formula for finding the specific S.G. when weighing in a liquid other than water is:

$$\frac{Wa}{Wa - Wl} \times CF = S.G.$$

Where:

Wa is weight in air
Wl is weight in liquid
CF is correction factor (the S.G. of the liquid in which the specimen is weighed.)

Present day practice, instead of using the very odorous and highly volatile carbon tetrachloride, merely adds a small amount of detergent to the water in the beaker. A drop or two of the Kodak wetting agent *Photo-Flo*, or of the liquid detergent *Joy*, or a small pinch of any good detergent powder such as *Vel*, answers the purpose very well. No correction factor is necessary when a detergent is added to the water.

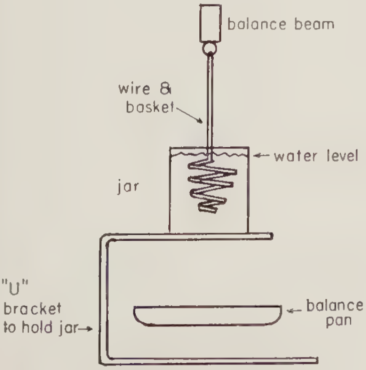


Fig. 19-3.

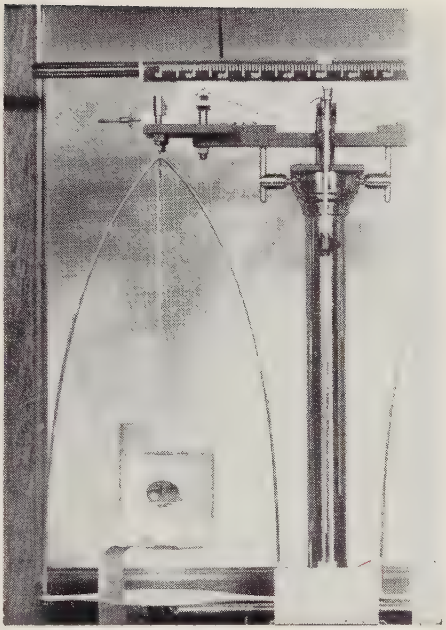


Fig. 19-2. A close-up of the left hand pan showing the wire with the hook and "basket" for holding the specimen while weighing in water. The U-shaped support holding the beaker of water must be so arranged that it cannot touch the regular weighing pan while weighing is being done, either in the pan or the basket in the water.

Specific gravity determinations by the hydrostatic method on stones below one-half carat are somewhat unreliable. When necessary, it is best to make at least three complete tests, starting from the beginning each time. An average of the results will be found usefully accurate.

Instead of a diamond balance, a good photo or darkroom scale may be used for stones above 1 gram (5 carats) and for moderate sized mineral specimens. The Eastman Kodak Company balance is very good. See Fig. 19-4.

To equip it for S.G. use, only a length of No. 16 to No. 20 copper wire, a drinking glass, and the end of a corrugated cardboard box are necessary.

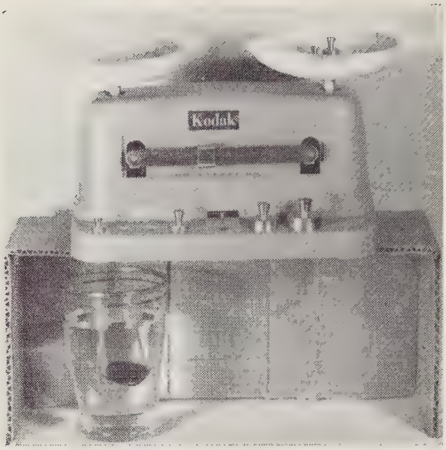


Fig. 19-4. An Eastman Kodak scale rigged for specific gravity testing.

With a sharp knife, cut one end from a box, as shown in the photo. Cut a 2- or 3-inch hole in the top of the box under the left end of the balance. Bend a short hook on one end of the wire. to be hooked over the bracket that supports the left pan where it is attached to the beam. Be sure it does not interfere with the movement of the beam.

Bend the other end of the wire into a basket to support the stone well under the water in the glass.

With the copper wire basket in the water, put something in the right-hand pan to counterbalance the weight of the copper wire, adding a few snippets of paper to complete a perfect balance.

With all of the above arrangements made, make the gem or mineral weighing tests the same as with the diamond balance. With the empty wire basket in the water, carefully weigh the stone in the left-hand pan. This is the weight in air (Wa). Then put the stone in the basket, be sure it is well immersed in water, and weigh it again to get the weight in water (Ww). Complete the calculations, the same as with the diamond balance.

Any units of weight can be used for S.G. calculations. Carats, grams, ounces, or tons are usable just so the same unit is used for the weight in air and the weight in water.

Heavy Liquids

The use of heavy liquids for S.G. testing is simple. The S.G. of the liquid is known. The stone is placed in the liquid. If it sinks it is of higher S.G.; if it floats it is lower in S.G. than the liquid.

In Chapter 5 we suggested the use of three heavy liquids: *methylene iodide*, S.G. 3.30 to 3.32. *Bromoform*, S.G. 2.89 or 2.90. *Bromoform diluted with xylene* (also called xylol) to an S.G. of 2.62.

The methylene iodide, though rather expensive, seems irreplaceable. Bromoform is also becoming expensive and more difficult to get. In lieu of bromoform we now suggest the use of *acetylene tetrabromide*. We were informed of this chemical by an industrial chemist who said that for S.G. use it had all of the advantages of bromoform and none of the disadvantages. It is cheaper, easier to obtain, and less volatile. It does not cause allergy troubles as bromoform does to a few persons. And, it does not turn black in strong light as easily as bromoform. It is as easily diluted with xylene as bromoform and methylene iodide. There are few if any disadvantages. Some say it has a stronger odor than bromoform. Possibly. Neither seems particularly bad, but certainly neither would be mistaken for attar of roses.

Acetylene tetrabromide, as purchased, is 2.96 in S.G. It can be used at this S.G. or diluted to 2.90 with a small amount of xylene. A little additional xylene gives an S.G. of 2.62.

Indicators

To mix or check heavy liquids, indicators or S.G. standards are needed. Indicators are small fragments or cut cubes of minerals of known S.G. Two are generally used. One should just sink and the other just float in the liquid. This gives warning of undesired dilution or evaporation of the diluent, which would make both float or both sink. Standards for S.G. are small rectangular pieces of glass calibrated and marked with their S.G. They are made to check the S.G. of heavy liquids.

Bromoform and acetylene tetrabromide, when used full strength, need no indicators. If diluted to a lower S.G., especially 2.62, they should have indicators. Two small fragments, one each of crystalline quartz and chalcedony, placed in the bottle of S.G. 2.62 liquid will indicate a change of S.G. When the liquid is of correct S.G. the crystalline quartz will sink and the chalcedony will float. If the liquid becomes too heavy due to evaporation of the diluent, the crystalline quartz will float. In this case, a few drops of xylene should be added to lower the S.G. If the liquid becomes too low in S.G., because of too much xylene, it can be left uncovered over night or gently heated for a few minutes until some of the xylene has evaporated.

When diluting these liquids, add the xylene with a medicine dropper. Add only a few drops at a time and mix it thoroughly by squeezing the liquid in and out of a clean dropper, between additions of the diluent.

Never use alcohol as a diluent. It evaporates out of the solution far too quickly to give a stable solution.

When no S.G. standard is available for diluting acetylene tetrabromide to 2.90, a small scrap of prehnite is about the right S.G. Dilute and mix until the prehnite remains suspended.

Methylene iodide is quite stable and due to its cost is seldom diluted. It needs no indicator.

Care of Liquids

For gemological use, a convenient amount of heavy liquid is about 1½ ounces in a 1-ounce wide-mouthed bottle or jar. Sounds funny? Not so. The liquid is *heavy*. The 1½ ounces will fill the 1-ounce bottle about half full.

All of the heavy liquids mentioned tend to darken rapidly if exposed to strong light. Ten or 15 minutes in actual sunlight will make methylene iodide or bromoform almost black. Acetylene tetrabromide darkens least. Form the habit of tightly capping each bottle immediately after use and always storing it in a covered box.

To inhibit this tendency to darken, a few short lengths of clean copper wire should be kept in each bottle of liquid. If, in spite of this precaution, the liquids do become rather dark, a small amount of clean mercury can be placed in the bottle and if it is shaken well most of the dark color will be removed.

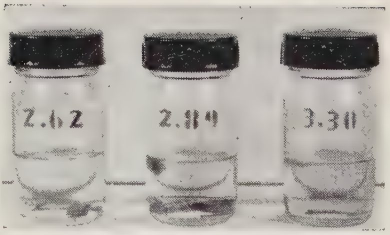


Fig. 19-5. A typical set of jars with the three most used specific gravity testing liquids.

Heavy liquids should be filtered through chemist's light filter paper after considerable use. This will remove the lint and silt that give them a murky appearance.

Those who mix or care for their own heavy liquids should note the type of liner inside the Bakelite bottle cap. The liquids have a rather destructive effect on some plastics. The clear, transparent plastic often used inside bottle caps is unsuitable and will soon soften and stick to the bottle, making the cap difficult to remove. If this trouble occurs, add another liner of the white, milky, sheet plastic, often used as wraps or envelope containers for the better grades of sliced luncheon meats. This plastic, polyethylene, is unaffected by the action of the heavy liquids.

When using heavy liquids the following precautions should be observed. *Place* the stone in the liquid with tweezers. Do not drop it in with the fingers as this may cause a splash and some loss of liquid. When removing a stone with tweezers, touch it to the neck of the bottle to remove excess liquid. If the stone is to be further tested in another liquid, always put it on a piece of hand tissue and blot to remove remaining liquid before placing it in the second bottle. This avoids contamination of one liquid with another and a consequent alteration of its S.G.

Accuracy

Unless the stone remains suspended in the liquid (neither sinking nor floating) this method does not tell the exact S.G. of the stone. But after a little practice, a close approximation can be made by carefully noting the specimen's rate of sinking or returning to the surface after being pressed to the bottom with the tweezers. This adds considerably to the practical utility of testing by the heavy liquids method.

Sets of three heavy liquids can be obtained from the Gemological Institute of America. The liquids can be purchased in bulk from chemical houses.

Sometimes bromoform can be obtained, or obtained more cheaply, only in a commercial form containing 4 per cent alcohol. The S.G. is about 2.62 but, because of the alcohol, the compound is unstable in use. The alcohol can be washed out with water, leaving the liquid about S.G. 2.90, after which it is quite satisfactory for use or dilution with xylene.

To wash, put the amount desired in a bottle with a similar amount of water. Shake briskly for about 30 seconds and permit to stand for a minute or two. The water quickly rises to the top and most of it can be removed by decanting or by suction with a medicine dropper. Do this two to four times. Then filter the bromoform through a chemist's medium filter paper which will remove the last of the water.

Here is a brief recap of the heavy liquids:

Methylene iodide, S.G. 3.30 or 3.32.

Acetylene tetrabromide, S.G. 2.96. Use at this S.G. or dilute to 2.90 with xylene.

Bromoform, S.G. 2.90.

Acetylene tetrabromide, or *bromoform,* diluted with xylene to S.G. 2.62.

Making Standards

For the gemologist who has access to a diamond balance equipped for S.G. testing and who desires to make one or more S.G. standards, the following easy method is offered. A diamond blade trim saw is necessary to rough-cut the glass or minerals used for the standards.

Most S.G. standards are of specially compounded glass cut to a size about ¼ x 7/16 x ⅛ inch. They are carefully checked for S.G. and marked to three decimal places. But the S.G. of the glass can be changed only when compounding the materials before melting.

Our method is superior because any desired S.G. can be obtained by grinding. The trick is to use two layers of glass or mineral, one heavier and one lighter, preferably about an equal amount above and below the desired S.G. Cement the two pieces together and grind off the sides until the exact total S.G. is obtained.

From rough slabs, 1/16 to ⅛ inch thick, of the selected materials, saw rectangles about 5/16 x ½ inch. Lap the pieces lightly with 220 or finer grit on a rotary lap or by hand on a glass slab and cement them together with a catalyst (epoxy) cement or with Glyptal. Lap the edges to the exact size desired but leave the cemented pieces thicker than the expected final dimension.

Let us say that the desired S.G. is 2.62 and that crystalline quartz and chalcedony are being used. If S.G. 2.90 is desired, quartz and tourmaline or beryl and nephrite can be used. These minerals are easily obtained and do not have to be of gem quality. Glass is excellent for either or both pieces if both high and low S.G. pieces are available.

Check the assembled unit carefully for S.G. on the diamond balance. If the S.G. is 2.64, hand lap the crystalline quartz side a little and recheck for S.G. If too much was ground off and the S.G. is 2.615, lap a little off the chalcedony side. When only a little is to be taken off use 400 or 600 grit. Try to check the S.G. to three decimal places each time and the final standard will be as accurate as your work and checking.

To our knowledge, this method of making standards has not been suggested before.

Chapter 20

Other Instruments and Methods

The dichroscope is a very useful instrument, inexpensive if purchased, easily made in the home workshop. It may be used to prove the identity of certain gems, but more often it will be used to prove or verify double refraction in a gem, always a big step toward identification.

A dichroscope made and sold by the Gemological Institute of America, costs about $10.00. Slightly more complicated British instruments are available, costing $12.00 to $16.00 plus import duty.

Figure 20-1, a drawing in cross section of the dichroscope, shows the simple construction. The principal part of the instrument is a small rhomb of optical calcite. The eyepiece is a simple lens of low magnification. A square or rectangular hole in the object end allows light from the stone being examined to enter the instrument.

Figure 20-2 is a drawing of the two-window effect seen through the instrument.

The principal of the dichroscope is based on the fact that light passing through a doubly refractive mineral is polarized and divided into two rays which vibrate at right angles to each other. These two rays are absorbed to different degrees by their passage through the mineral structure and travel at slightly different speeds.

Color in gem minerals is caused by a process called *selective absorption*. If all wave lengths of light pass through a stone with equal ease, the stone will appear colorless. If all wave lengths are absorbed, the stone is opaque. If wave lengths other than blue are absorbed, and blue passes through, the stone will appear blue.

Light rays passing through a singly refractive mineral are equally absorbed whatever their direction of vibration. But in passing through a doubly refractive mineral, the horizontally vibrating rays and those vibrating vertically are absorbed differently. One polarized ray will be slowed down more than the other, and a different color will emerge.

The human eye cannot separate these differently polarized rays, so colors emerging from a doubly refractive gem blend together to make up the apparent color of the stone. The calcite in the dichroscope separates them and makes the different colors separately visible.

Therefore, if dichroism is to be visible in a gemstone, first, it must be a *colored* stone. No color, no dichroism. Second, the stone must not be singly refractive. Third, if doubly refractive, it must not be viewed along a direction of single refraction. No dichroism can be seen in a direction of single refraction.

As explained in a previous chapter, uniaxial minerals have one direction of single refraction, called the optic axis. Biaxial minerals have two directions of single refraction, two optic axes along which no dichroism can be seen.

Fig. 20-2. (a) The windows of the dichroscope are usually seen offset like this. (b) The direction of vibration of light rays as seen through the dichroscope.

Fig. 20-1.

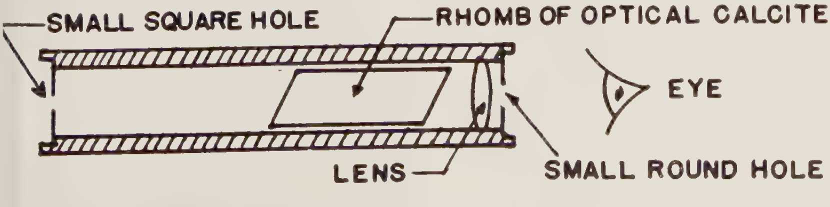


Fig. 20-3. The best way to use a dichroscope is to hold it close to the gem, using a good lamp such as this microscope substage lamp for illumination.

Light entering a singly refractive mineral meets the same optical resistance in all directions so it is not polarized.

In uniaxial minerals there is one axis of different length from the others, causing the light to be polarized and divided into two rays; these, being differently absorbed, emerge as two colors.

In biaxial minerals there are three different axial lengths, three different possible directions of light vibration, and when viewed from the right directions, three colors may be seen with the dichroscope, two colors when viewed from one direction, one of these and another color when viewed from another direction.

Minerals showing two colors are termed *dichroic,* those showing three colors, *trichroic*. The inclusive name for these effects is *pleochroism*.

Biaxial minerals do not always show three colors. Two of the three axial directions may show the same color. The mineral is then called dichroic.

To use the instrument, the stone is held toward a window, or any moderately strong source of white light. Best of all, place the stone on the lighted window of a microscope substage lamp. The dichroscope is held quite close to the stone, as close as possible without touching. Look through the instrument; the eyepiece end has a round hole. Fig. 20-2 shows the appearance of two windows as seen through the instrument. Fig. 20-3 shows how to hold the instrument over a gem on a substage lamp.

Do not expect any violently contrasting colors such as green and orange. Color differences are subtler, often only a difference in shade of the same color, such as dark and light blue. Dichroic colors of ruby are purplish red, and orangy-red. For andalusite, dark red, brownish yellow, and grayish green; it is trichroic.

The vividness or strength of colors seen in the dichroscope is described by the words *strong, distinct, weak.* The word *very* may be applied to the first and last of these. All four words are frequently abbreviated by using the first letter, such as S (strong), or VS (very strong).

When viewing a gem through the dichroscope it is usually necessary to turn or rotate the instrument to pick up the maximum color difference. If no dichroism is seen, turn the stone and observe it from a new angle. This should be done two or three times to be sure it has not been viewed along a direction of single refraction.

An occurrence in our class in gem identification will illustrate how necessary it is to observe the stone from different directions. A small, flat crystal fragment was listed for over two years as pyrope garnet. Pyrope is singly refractive and can never show dichroism. No inclusions were visible through the small spot polished for the taking of refractive index. We will never know how many times it had been identified as pyrope, nor how many had misidentified it (we thought) as ruby. One bright young man called our attention to the error in its identity by saying, "I don't see how you can call it pyrope when it is so strongly dichroic. *Just look at it through the edge*." Sure enough, it did show strong purplish red and orangy-red colors through its edge, the colors so typical of ruby. No one had ever carried the test far enough to find the dichroism.

In some stones the colors are very vivid, in others one or both colors may be very faint. Constant use and practice will develop the ability to recognize the color differences.

Polarized light must not be used with the dichroscope. For instance, if a gem is placed on the lower polaroid of a polariscope, when viewed through the dichroscope it will appear strongly dichroic, even if it is glass or diamond, because of the polarized light passing unchanged through the singly refractive stone.

Sometimes a false impression of dichroism may result when light is reflected from certain facets of a stone under examination. Light reflected from any surface is partially polarized and light reflected from facets at a particular angle may closely simulate dichroism. When this effect is supected, rotate the dichroscope 180 degrees (turn it half-way around) and note whether the colors seen in the two windows reverse their position with the turn of the instrument, or remain on the same side. Say dark blue is seen in the left window and light blue in the right window. If, when the instrument is reversed, the light blue then appears in the left window, it may be considered true dichroism. If the colors remain in the same position it is not true dichroism.

The direction through a stone in which dichroism is observed may *indicate* but not prove the synthetic or natural origin of the gem. Synthetic ruby is produced in the form of pear-shaped boules which are under considerable internal strain when cooled. The strain can be relieved by an additional heat treating process but, because of the cost, this is not commonly done. The same relief of strain can be accomplished by splitting the boule, either by breaking off the small tip or by striking the small end of the boule with a light hammer. The split boules offer rough material of semicylindrical form for cutting into gems, leaving little option in orienting them for cutting. A large percentage of commercially cut synthetic ruby is cut with the table parallel to the long axis (optic axis) of the boule and shows strong dichroism when viewed through the table. To display the best color, natural rubies are usually cut with the table at right angles the optic axis and they seldom show strong dichroism when viewed through the table.

Use of Polariscope

The polariscope may be used to show dichroic colors. The stone is held over the lower polaroid, with the top polaroid removed or turned to *light* position. If the stone is dichroic, one color at a time will be seen as the stone is rotated. This method is less sensitive to weak color differences because the colors are not seen side by side for contrast.

Do not depend too greatly upon dichroic colors as reported in books of gem data for proof of the identity of a gem stone. The colors seen vary with the color of the mineral, as well as with the depth of its color. But if dichroism is definitely seen, it does prove double refraction, often a very big step.

Only a limited few gems have sufficiently distinctive dichroic colors to offer proof of identity. Ruby, purplish red and orangy-red are distinctive but are the same for synthetic or natural. Benitoite, dark blue and colorless; kunzite, light red or pink and colorless, are two more. There are, perhaps, others known to experienced gemologists.

We have explained the more important gem testing instruments, but before proceeding with actual identification explanations, there are a number of less used items of equipment that should be explained and considered.

Some are infrequently used, but when necessary, they may be time savers. Or when complete equipment is unavailable, they may offer reasonable proof for an identification.

The Spectroscope

Foremost in this class of minor instruments (British gemologists will hate me for this) is the spectroscope. Not fully appreciated and infrequently used by American gemologists, the spectroscope is too often considered essentially a British instrument, necessary to the American gemologist as "fancy fixin's" only. But every American gem testing *laboratory* has one or more!

Most suitable for gemological use are the hand-held instruments made by R. & J. Beck, of London, costing $15.00 to $30.00 in England; about $40.00 to $60.00 here. Fig. 20-4.

A spectroscope allows white light to enter through a narrow slit in the end, after which it passes through a diffrac-

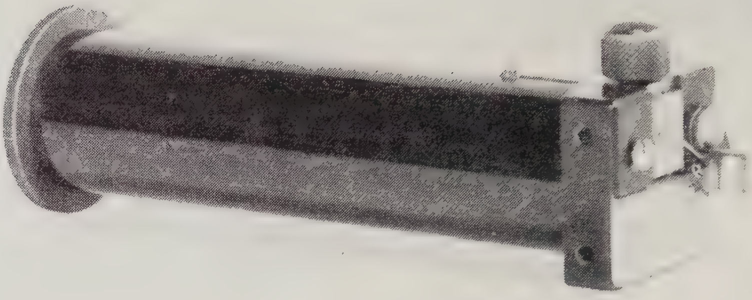


Fig. 20-4. A typical hand spectroscope used for gem testing. The slit is adjustable and on the end to the right. The eyepiece is on the other end.

tion grating or a series of three to five glass prisms. The dispersion of the prisms or grating separates the white light into its component colors. This spectrum of colors is seen through the eyepiece of the instrument.

Hand-held spectroscopes are available in two types. One uses a diffraction grating which disperses the light evenly, showing each color of the spectrum in bands of the same width. It requires a fairly intense light source. This type disperses the light about 20 to 34 degrees.

The second type, using a series of glass prisms to disperse the light, requires much less light for efficient operation but concentrates the colors at the red end and spreads them at the violet end. In this type the dispersion is about 10 degrees. Both types are satisfactory for gem testing. But because of the intense light required, fewer of the grating type are in use for this purpose.

Testing of gems with the spectroscope might be compared with the candling of eggs. The white light, instead of entering through the slit unimpeded, is directed through the gem, the light then entering the instrument.

Color in gem stones is the result of selective absorption of light passing through the stone. A colorless gem is one that has passed all colors equally.

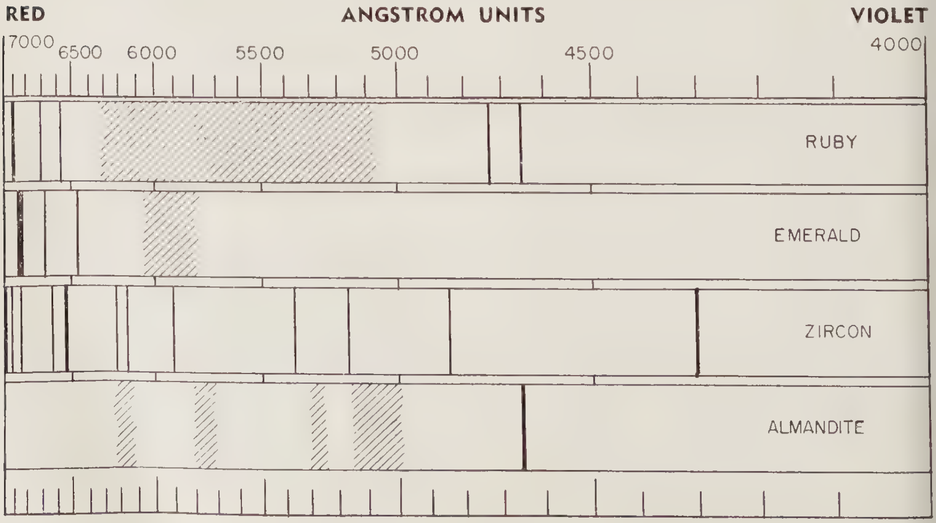


Fig. 20-5. **ABSORPTION BANDS FOR SOME COMMON GEM STONES**
The bands appear as dark lines across the colors of the spectrum.

Light absorption in gems results from certain metallic elements present in the stone's composition. Some elements absorb narrow, sharply defined bands of color; others wide bands, much less sharply defined. The purpose of the spectroscope is to make these *absorption lines* or bands visible as they occur across the spectrum of colors seen in the instrument.

Colorless gems show no absorption lines. Only a limited number of common colored gems absorbs enough light to cause visible lines in the hand spectroscope. If all gems caused identifiable absorption lines, the spectroscope would indeed be the ideal instrument. To the gemologist experienced with the spectroscope, identification of a gem may result as much from the absence of certain lines as the presence of others.

The black and white drawings will give some idea of how the absorption lines look in the prism spectroscope, but we can indicate the colors only by the wave length figures in angstrom units; 4000 AU, to the right, is the violet; 7000 AU, to the left, is the red end of the spectrum. Fig. 20-5.

Those interested in more details of the spectroscope and its use, will find the following books useful: *Gemstones* by G. F. H. Smith, *Gem Testing* by B. W. Anderson, *Gemmologists Compendium* by Robert Webster.

Color Filters

Often called *Chelsea filter,* or *emerald filter,* color filters are intended as a test for emerald versus glass and other imitations of emerald. They are much like an olive green photographic filter, usually metal bound for ease in handling. They cost about $3.00 to $5.00. Fig. 20-6.

A filter, as the name implies, absorbs or filters out certain wave lengths of color from the white light. The emerald filter absorbs all wave lengths except red and green; therefore, a stone observed through the filter must appear in some shade of one or the other of these colors.

In use, a well illuminated stone is observed through the filter and the resultant color noted. Emerald and glass of the same color (to the eye), will appear quite different through the filter. Emerald will appear a deep red, glass will be green. The depth of the stone's color may affect the color seen through the filter. The deeper the green of the emerald, or the more blue there is in the green of the stone, the deeper will be the red seen through the filter. An emerald of light green will appear an uninteresting pink.

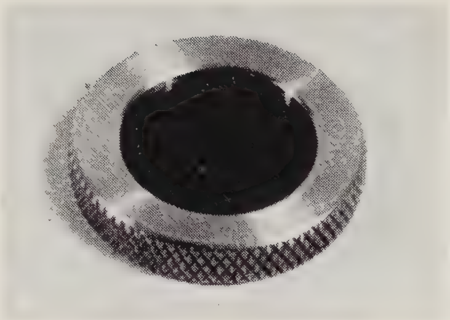


Fig. 20-6. Chelsea or emerald filter, used for testing emerald vs. glass imitations.

Green doublets and triplets appear green.

An emerald filter is not expected to offer proof of the synthetic (cultured) or natural origin of an emerald. But it does offer an excellent indication of the origin. Natural emerald viewed through the filter appears a deep red, while synthetic (Chatham) emerald appears a much more vivid, an "alive" red. All stones we have seen and tested show this difference, but we are informed that it is not true in all cases.

Recently the G.I.A. called the attention of the jewelry trade to stones of light green emerald with a green coating of plastic on the back which gave the stones a darker, more desirable emerald color. As might be expected, they answered ordinary tests for emerald but viewed through the emerald filter, the plastic appeared red and under ultraviolet light the stones fluoresced yellow.

Fluorescence

The use of ultraviolet light is occasionally of value in gemology to induce fluorescence in gem materials. Wave lengths of 2537 AU (short wave) and 3650 AU (long wave) are used. Lamps of either type are easily purchased from many dealers.

Many minerals fluoresce about the same under either wave length, but not all. Jeweler gemologists seem to use lights of long wave length more extensively. Rockhounds use the short wave to better advantage.

About 20 per cent of all diamonds sold will fluoresce about equally under long and short wave. Most diamonds fluoresce a light blue but occasionally other colors are seen. In general, jewelers completely ignore the phenomenon.

One of the commonest methods of determining the natural or synthetic origin of emeralds is through the use of ultraviolet light. Normally, natural emerald remains dark. Synthetic emerald fluoresces a very dark red.

To make the test, the emerald is placed on a completely black background and the ultraviolet light held very close. A dark red fluorescence will be seen if the stone is synthetic, no fluorescence if it is natural. It is said that one particular mine in Colombia and mines in India produce emeralds that do fluoresce to some degree but less than the synthetic. If suspicion of such origin occurs, the type of inclusions evident under the microscope will decide the matter. Short or long wave length U.V. light may be used but the short wave induces a little greater fluorescence.

Rubies, both synthetic and natural, fluoresce a deep, beautiful red. Usually the synthetic fluoresce more vividly.

Scheelite, both gem quality and opaque, fluoresces a vivid, steel blue under short wave for practically perfect identification.

Hyalite opal, some opalite, and an occasional gem opal fluoresce greenish yellow under short wave. Some chalcedony and petrified wood fluoresce yellow or greenish yellow under short wave. Benitoite fluoresces light blue under short wave. Some colors of zircon and of sapphire fluoresce.

Plastics and glass often fluoresce under either wave length. Crystals of halite (rock salt) fluoresce an orangy red under short wave.

Streak Plate

Always part of a mineralogist's equipment, a streak plate occasionally can be useful to the gemologist. A streak plate is any flat surface of unglazed ceramic. Plates are obtainable from any mineral supply shop, but more commonly used are the small, unglazed floor or wall tiles, like the back side of bathroom tiles.

In use, the mineral is dragged with steady pressure across the unglazed surface. The resultant streak on the ceramic then is observed carefully for color.

Can you remember an earlier Chapter which explained the difference between allochromatic minerals in which the cause of color is an impurity, and idiochromatic minerals in which the cause of the color is an inherent part of the mineral's composition?

On a streak plate, idiochromatic minerals usually leave a colored streak. Allochromatic minerals, even if highly colored, will leave a colorless streak.

Minerals are often met that are too hard to test on a normal streak plate which is 5½ to 6 in hardness. When this occurs a sawed but not polished section of colorless synthetic corundum boule may be used.

Rough minerals may be tested freely on a streak plate. When necessary, a cut stone may be tested by placing the girdle down on the plate.

Actually there are few cases in which a streak test is necessary on cut stones. One case, however, is to differentiate between hematite (Fe_2O_3), a natural mineral often used as carved intaglios in men's rings, and Hematine, a proprietary material of similar composition, which may be moulded. Hematite leaves a red streak. Hematine generally leaves a black streak but occasionally a streak of dark brown. Another difference between these two materials is that hematite has a fibrous or splintery fracture, Hematine a conchoidal fracture. Small fractures on the girdle of unmounted stones may be found and examined with a loupe or microscope.

Malachite leaves a green streak.

The dark streaks imitating matrix in the modern imitation turquois leaves a black streak. The blue areas in imitation turquois leave a white streak as it is pulverized turquois with a plastic binder.

Hardness

Hardness is defined as "scratch resistance" by the G.I.A., and called "scratchability" by mineralogists. Tests for hardness are frowned on and seldom used by gemologists but must be understood so they may be used properly in the few instances when necessary.

Tests for hardness consist of finding in some way whether one material is harder than another. The old-time jeweler casually tested many gems for hardness by attempting to scratch them with the sharp corner of a broken-tipped file, considering that if it scratched, the gem must be glass.

Proper hardness testing should be done with hardness points or plates. Hardness points consist of small mineral fragments set in the ends of metal tubes, something like small, short pencils. Fragments of each mineral listed in Mohs' scale of hardness, from 1 to 10, make an excellent set. More commonly used are those from 5 to 9. The softer ones below 5, and diamond as 10, will be used infrequently.

Instead of hardness points, individual mineral fragments of fingertip size are convenient. These often can be selected from one's own collection. Sharp corners, rather than fine gem quality, are required.

Hardness plates are conveniently sized mineral fragments with at least one flat sawed, but not polished, surface.

Hardness points are used when testing on the back of opaque cabochons. Transparent cabochons and faceted stones are best tested on hardness plates, the girdle of the gem being dragged across the surface of the plate.

All gem hardness testing consists of attempts to scratch one mineral with another. Heavy scratching and repeated scratching are seldom necessary. If a point is to be used, drag it firmly across the mineral's surface. Wipe the surface with the finger and examine the specimen with a loupe to see whether an *actual* scratch was made. If a scratch has resulted, it is proof that the point is *as hard as or harder* than the mineral. If no scratch is made try a harder point. Minerals of the same hardness will scratch each other but heavier pressure is needed than is necessary to scratch one of lower hardness.

If it is necessary to test a faceted stone with a file or hardness point, put the scratch on the girdle and make it small. Never deface a cut stone.

For this reason, cut stones are safer if tested on hardness plates. Steadily drag the girdle of the stone across the surface of the plate, wipe off the streak and examine the plate for an actual scratch which will prove the stone is as hard as or harder than the plate.

Always wipe off the streak which results from the scratch attempt, regardless of which is harder, before looking for an actual scratch on the stone or plate. A streak always appears and looks much like a scratch, but it may have come from either mineral.

Testing Mounted Stones

The testing of mounted stones may require some special techniques and precautions, as not all of the customary tests can be made.

Specific gravity cannot be obtained except by removing the stone from its mounting.

It is often necessary to clean a stone mounted in a ring before it can be tested or clearly observed. A quick scrubbing with an old toothbrush, Ivory soap and warm water is usually sufficient.

If the stone is transparent, a polariscope and dichroscope will indicate single or double refraction. Stones mounted in settings with closed backs or in gypsy mounts are especially difficult. But if held in the hand and turned in all directions in the polariscope, it may be possible to get light through the stones. If the stones are colored, the dichroscope may help to indicate single or double refraction.

Most mounted stones can be tested for R.I. on the refractometer. Turn the stone table down and balance it on the refractometer hemisphere for a reading. If it is a cabochon, the mount may be held in the fingers and the stone touched lightly to the hemisphere for a spot reading.

Raised prongs or large mountings may make readings on the refractometer impossible. When this occurs it may be necessary to dismount the stone if positive identification is required.

If an emerald cut diamond set in a fine ring mount is being examined, and especially if the stone has been set so the prongs or parts of the mount make the stone difficult or impossible to place on a refractometer, there is the definite possibility of the stone's being an imitation diamond.

Colorless synthetic spinel, when emerald cut and well polished, is an excellent imitation diamond not easily identified if a refractometer cannot be used. Synthetic spinel will give a reading of 1.73 on the refractometer; a diamond is over the scale.

Both stones are singly refractive, but synthetic spinel will show anomalous double refraction in the polariscope, a diamond seldom does. In such cases, use the microscope or a good loupe. Small bubbles are usually seen in colorless synthetic spinel. But if there are no bubbles remember that most diamonds have typical inclusions to indicate the stone's identity.

As a last resort only, a silicon carbide pencil or a sharply tipped crystal of this material may be touched to an inconspicuous spot on the stone. On a diamond it will have no effect. Synthetic spinel will be scratched easily.

A method of obtaining the approximate refractive index of mounted stones is to immerse them in one of the S.G. liquids. In the case mentioned above where the possibility exists of synthetic spinel's having been used to imitate diamond, the immersion of the ring in methylene iodide (S.G. 3.30, R.I. 1.74) will offer immediate proof. Synthetic spinel, having nearly the same R.I., will almost completely disappear in the liquid. This method of R.I. testing was explained in a previous chapter.

Acid Test

The use of acids or other chemicals in identification is commoner in the science of mineralogy than in gemology. But occasionally the gemologist may find it a necessity or, perhaps, a convenient short cut.

The commonest chemical test is a touch of hydrochloric (muriatic) acid to any of the following: calcite, aragonite, coral, shell, pearl, bone, ivory, azurite, malachite, smithsonite, rhodochrosite.

Use a toothpick, touch the tip to the acid, then to the back or an inconspicuous part of the stone. Observe the action of the acid, whether it effervesces or remains inert on the small area affected, using a loupe if necessary. The stone should then be washed.

Copal or kauri gum, a resin from the kauri pine of Australia, may be used to imitate amber. Copal is softened by ether or turpentine, amber is not. A small drop of the liquid, after a few minutes on the surface of the material, will cause it to become soft and sticky.

Chapter 21

Practical Gem Identification

So far we have explained much about gems, their sources, their nature, and their properties. We have explained the scientific apparatus and equipment used in gem testing, and have detailed many individual gem tests. We will now explain how to put the equipment and methods of testing to practical use. We will have to assume that the previous lessons have been read and largely assimilated.

As all gemologists know, gem testing is highly individualistic. The sequence of applying the various tests to a gem varies with the type of gem being tested as well as with the experience and habits of the gemologist. Opaque gems require somewhat different methods from those used with transparent stones.

Whatever the sequence of testing, all tests are for the purpose of *eliminating* gems impossible of consideration. The process is one of elimination.

The first test is always a visual examination. Even at the very first glance the process of elimination commences. If the stone is colorless and transparent one knows without further consideration that it cannot be a ruby, lapis lazuli, emerald, or any other gem that by the nature of things and the definition of its identity, cannot be colorless and transparent.

Some of the elimination is by conscious mental effort, some is quite subconscious. The amount of each varies with the experience of the gemologist.

First Test

A great deal can be learned by merely examining a stone. At once apparent are its color and degree of transparency. Luster can be noted on polished surfaces and on any fractures evident, as well as any noticeable difference in degree of luster on parts of a stone, as may be seen on the garnet and glass parts of a doublet.

Any phenomena, such as chatoyancy or asterism, or the color change of alexandrite, will be evident at once. Dispersion or the lack of it may be observed in faceted gems. The high birefringence of stones such as zircon and synthetic rutile may be evidenced by a fuzzy appearance of the stone's interior.

The shape of a fracture can be seen whether it is conchoidal as in most stones, or uneven as in feldspars, spodumene, and others of easy cleavage.

There is one stone usually identified at a glance. Synthetic blue spinel may be separated from other blue stones by observing it under a good light. As the stone is turned, bright red flashes will be seen from some of its facets. An occasional stone of blue synthetic spinel may not show red flashes but they are never seen on synthetic sapphire or on natural stones.

When observing a stone if it is unmounted, weigh it in the hand. This is called "hefting" by the mineralogists, and while it may seem a rather inexact method of S.G. testing, serves to separate the featherweight amber and plastics, stones of medium density, such as quartz, corundum, and topaz, from those of higher S.G. like strontium titanate, scheelite, and cassiterite—stones above 5 S.G.

Second Test

Some consider the second test should be that of higher magnification. However, if the stone is transparent, we usually test for single or double refraction with the polariscope.

Instead of dropping the stone into the cup above the polarizer of an American open-style polariscope, experience has taught us that there is usually an advantage in holding the stone in the fingers, unless it is quite small. In this way the stone can be rotated, turned, and again rotated, most easily.

If sufficiently transparent to permit light to pass through, cryptocrystalline or crystalline aggregate material will be indicated by the stone's remaining light when being rotated.

Singly refractive gems will remain dark or show the patchy extinction of anomalous double refraction.

Doubly refractive gems turn alternately dark and light, dark very briefly and light rather longer, as they are rotated. A doubly refractive gem is said to show extinction.

Singly refractive gems that are under some internal strain, as are most red garnets, often show the extinction of true double refraction. Because of this, red gems appearing doubly refractive should be further tested with a dichroscope.

Other useful information may be gained during the polariscope test. If the stone is transparent and not too dark in color, watch carefully for the appearance of interference colors while it is being rotated between the polaroids. In doubly refractive gems, interference colors are seen only in the direction of the optic axis.

As the stone is turned and the point is reached where those brief, sometimes rather intense flashes of color are seen, hold a glass ball over the colors and note the shape of the optic figure which will indicate the optic character of the gem. The finding of optic figures in the polariscope was explained in Chapter 17.

Third Test

An excellent third test is for refractive index on the refractometer. Normal procedure is to place a small spot of refractometer fluid on the instrument hemisphere, clean the stone by rubbing it several times across folded tissue laid flat on the desk, then place it table down on the hemisphere.

Read the R.I., then rotate the polaroid disc a quarter-turn over the eyepiece and note any change in the R.I. reading. The R.I. line moving up and down, as the polaroid is turned, offers proof or verification of double refraction.

Turn the stone on the hemisphere slightly, perhaps an eighth of a turn or less, and again rotate the polaroid and check the R.I. After three or four slight movements of the stone on the refractometer one may be sure that maximum and minimum readings have been taken. Generally, the lesser reading subtracted from the greater gives the birefringence.

Optic character and sign of the mineral often may be found through the use of the refractometer but this should not be attempted unless later found to be necessary.

Fourth Test

A test for specific gravity of the stone should be the fourth test. Usually it is sufficient to place the stone in one of the bottles of heavy liquid to see whether it will sink or float. If it is placed in the 2.90 liquid and sinks rather quickly, try it next in the 3.30 liquid. If it floats in the 2.90 liquid, try in the 2.62.

If it sinks in a liquid, try raising it with the tweezers and note carefully the speed at which it sinks. If it floats, push it to the bottom and watch it rise. After some experience, a close approximation of the actual S.G. of the stone can be made based on the speed of sinking or rising.

In some cases an approximation of the S.G. is insufficient for proper identification. The hydrostatic method of checking S.G. has been explained. When carefully done it will give the S.G. of a stone to three decimal places, quite sufficient for gemological work. S.G. to two decimal places is usually adequate.

The hydrostatic method has some disadvantages. It is inaccurate for stones under one-half carat. Heavy liquids will work as accurately on small as on large stones.

Each method may supplement or prove data obtained by the other method. If an S.G. of 3.20 has been obtained by the hydrostatic method, drop the stone in the bottle of 3.30 liquid, push it to the bottom, and watch it rise slowly. This offers proof of the accuracy of the previous test.

Fifth Test

Magnification should be the next test. Careful use of a loupe or a microscope will show up any distinctive inclusions such as curved striae, bubbles, negative crystals, etc.

Magnification is almost always necessary to distinguish between natural and synthetic sapphire or spinel. Magnification is usually necessary to distinguish between natural and synthetic emerald.

These are the commonest, the routine tests in identification of gem stones. Each of the five tests should eliminate certain gems from the first list of possibilities. The first test, that of visual examination, will eliminate the gross impossibilities such as opaque and phenomenal stones, if the stone being tested is transparent.

The second test using the polariscope and the dichroscope will establish the stone as singly refractive or doubly refractive and eliminate all stones in the other category.

The third test, obtaining the refractive index and birefringence eliminates those of higher or lower R.I.

The R.I. test sounds rather conclusive but due to normal variations in R.I. of most minerals, and the overlapping of some, it must be combined with other properties before a conclusion can be reached.

Specific gravity, the fourth test, by whatever method obtained, again eliminates those gems of higher or lower S.G.

After the S.G. is obtained, as with R.I., a certain range or possible plus or minus variation must be allowed. The amount of possible variation will depend upon the method and equipment used for the test.

At times the S.G. test is unreliable or perhaps cannot be used at all. If a stone is mounted, S.G. is unobtainable except by dismounting the stone. Some turquois is rather chalky in appearance, may absorb some of the heavy liquid, and be unreliable in any S.G. test. Gems with metallic inclusions, such as lapis lazuli with pyrite, agate with marcasite, and gems with gold lodge emblems inlaid, and assembled stones, will yield unreliable results if tested for S.G.

The fifth test, magnification, is needed to separate most synthetics from their natural counterparts. Magnification is almost always needed to separate synthetic from natural corundum. Curved striae or spherical inclusions in the synthetic, angular inclusions in the natural, are the main indicators.

A slight difference in R.I. between synthetic spinel and natural spinel, together with the anomalous double refraction usually seen in synthetic spinel when tested in the polariscope, may make it unnecessary to use the microscope. But synthetic spinel often has bubbles the same as synthetic corundum. Curved striae are not seen in synthetic spinel.

The microscope usually separates synthetic from natural emerald. Wispy inclusions in the synthetic, three-phase inclusions in the natural, are what to look for.

Several gem minerals have rather distinctive inclusions which may identify or greatly aid in their identification. Chief among these is demantoid garnet with horsetail inclusions.

After considerable experience in gem testing, it will seldom be necessary to complete all the above tests. Short cuts can be made by leaving out tests that do not apply or are unnecessary. It is useless to attempt taking the R.I. of the metallic opaques such as pyrite, hematite, and marcasite. Little can be gained by testing for S.G. of red garnets because they overlap in this property.

Until one gains considerable experience, gem testing must be done by carrying out all tests with continual reference to gem data tables.

Chapter 22

Gem Testing Problems

Some experience and practice in gem testing can be gained without instruments, by carefully working out the following problems and others like them. The problems resemble what the football coach used to call "skull practice," remember? We can call it "paper practice," but it does require some thought.

Practice Problem No. 1

If an unmounted, brilliant-cut gem, transparent, and blue, is considered for identification, proceed as follows: First make a scratch paper list of all blue stones. Leave out those that are almost always opaque or translucent, such as azurite, chrysocolla quartz, dumortierite, lapis lazuli, turquois, lazulite, sodalite. But include all the transparent gems, whether light or dark blue.

The gem names may be obtained from the color chart in the appendix (except glass, plastics, doublets, triplets, and foil backs, which may be found in any color and are not listed in color tables.)

Arrange the names in tabular form. A particular sequence is unnecessary.

As each test is made, theoretically or actually, put a check mark in the proper column for each stone *eliminated* by that test.

Test No. 1, Visual Examination. The only gem that can be eliminated after this test is the *foil back.*

Test No. 2, Polariscope and Dichroscope. Rotated in the polariscope, with the polaroids crossed, the blue stone turns light and dark, proving double refraction, and eliminating all singly refractive gems. Six are eliminated: *diamond, fluorite, spinel, synthetic spinel, glass, and plastics.* Doublets and triplets may be either singly or doubly refractive.

If the dichroscope is used, the gem shows violetish-blue and greenish-blue. Finding the two colors again proves double refraction. It also eliminates *benitoite,* which appears blue and colorless through the dichroscope.

In general, the dichroscope is used only to prove or verify double refraction. But there are a few gems that show distinctive colors, and benitoite is one of them. The dichroscope should invariably be used as a check for double refraction on all *red* stones that appear doubly refractive in the polariscope.

Test No. 3, Refractive Index. On the refractometer, the stone shows a clear line of 1.76. When the polaroid plate is rotated over the eyepiece of the refractometer the colored line jumps to 1.77, indicating a birefringence of about .010.

Allowing for a reasonable variation in R.I., eliminate all gems that are not within approximately 5 points (in the second decimal) of 1.76. On this basis eliminate: *diamond, euclase, fluorite, iolite, kyanite, quartz, topaz, tourmaline, and zircon.*

Glass may be eliminated as in jewelry stones it never goes higher than 1.70 in R.I. Also, Test 3, by showing two readings, has again proven the gem to be doubly refractive, and glass and plastics, as well as spinel and synthetic spinel, should again be eliminated as being S.R.

At this time, remaining unchecked on the list, are sapphire, synthetic sapphire, doublets, and triplets.

Test No. 4, Specific Gravity. Place the stone in the 3.30 S.G. heavy liquid bottle. It sinks quite rapidly, indicating that it is well above the density of the liquid. Check off all gems of 3.30 or below.

At the same time, an immersion test for doublets and triplets can be accomplished by carefully looking for a separation plane in the stone while it is immersed in the liquid. If a plane separating the parts of an assembled stone is not present, check *doublets and triplets* as being eliminated. Remaining unchecked are sapphire and synthetic sapphire.

Test No. 5, Higher Magnification. A loupe may be sufficient if the inclusions are medium or large, but a microscope with at least 10X and 30X is practically a must for establishing the origin of most synthetics. The gemologist will view with suspicion any gem that may be made by man if no inclusions are visible under low magnification.

Putting our stone under the microscope at 30X we see some silky inclusions. Upon raising the power to 60, we are able to see three sets of fine needlelike inclusions in the same plane and at about 60 degrees to each other.

Such inclusions prove the stone to be natural and, as such inclusions are common in sapphire, we will check, as eliminated, *synthetic sapphire* and all other gems on the list.

During the examination with the microscope we can again check the stone for the separation plane seen in doublets and triplets. Double check and try to prove, by a second set of tests, all previous eliminations.

This stone has been proven a natural sapphire.

Practice Problem No. 2

Here is another problem. Work it out and check your answer with our answer and explanation at the end of the chapter.

From the color description given in Test No. 1, select gem stones you consider possibilities from the color table in the appendix. List these stones vertically, followed by five columns, one for each test, to make a check chart. For each test put a check mark in the proper column after the stones you consider *eliminated by that test.* Leave the space empty if the stone is retained as a possibility. Consider every gem stone in each test, put a check if the stone is eliminated even if the stone was eliminated by a previous test. This gives additional proof for some tests and may help to correct errors.

Test No. 1, Visual Examination. Stone is light yellow, transparent, brilliant-cut. No scratches, fractures, or apparent

EXPLANATION OF PROBLEM 1

Test No. 1, Visual Examination

Stone is blue, transparent, brilliant-cut, unmounted.

Check Chart Problem 1

GEM NAME	1st TEST	2nd TEST	3rd TEST	4th TEST	5th TEST
Diamond		X	X		X
Sapphire					
Syn. Sapphire					X
Benitoite		X			X
Euclase			X	X	X
Fluorite		X	X	X	X
Iolite			X	X	X
Kyanite			X		X
Quartz			X	X	X
Spinel		X	X		X
Syn. Spinel		X	X		X
Topaz			X		X
Tourmaline			X	X	X
Zircon			X		X
Glass		X	X		X
Plastics		X	X	X	X
Doublets				X	X
Triplets				X	X
Foil backs	X				X

cleavages. Luster appears vitreous.

What gems do you consider possibilities?

Which should be eliminated as the result of Test No. 1?

Test No. 2, Polariscope and Dichroscope. Stone turns alternately light and dark when rotated in the polariscope.

What is your interpretation?

Which gems will you eliminate as the result of Test No. 2?

Test No. 3, Refractive Index. With the stone on the refractometer, a reading is seen at 1.62. When polaroid disc is rotated over the eyepiece, and after turning the stone slightly a few times, the R.I. reading moves up and down only a little.

What does this indicate?

Which gems will you check off?

Test No. 4, Specific Gravity. The stone is placed in heavy liquid, S.G. 3.30. It sinks rapidly. No separation plane is visible.

What is your interpretation?

What stones should be checked off?

Test No. 5, Magnification. Two small needlelike inclusions are seen, extending through the stone. They are unnoticeable to the unaided eye.

What has been accomplished by this test?

What is the stone?

Practice Problem No. 3

Test No. 1, Visual Examination. Stone is blue, transparent, brilliant-cut, well proportioned, with very high luster. No scratches or cleavages, but some pitting is visible at the girdle and facet junctions.

What gems do you consider possibilities? Make up your list.

Test No. 2, Single or Double Refraction. In the polariscope the stone turns dark four times and light four times during a complete revolution. Through the dichroscope, two colors are seen, light blue and gray.

What is your interpretation? What gems can be eliminated by Test No. 2?

Test No. 3, Refractive Index. With stone properly placed on the refractometer, the entire scale seems to be shaded, no definite color line can be seen, even after the stone has been turned and tried again.

What is your interpretation? What gems can be eliminated by Test No. 3?

Test No. 4, Specific Gravity. When stone is placed in 3.30 heavy liquid it drops to the bottom very quickly. During its immersion, no separation plane is seen.

What is your interpretation? What stones may now be checked off?

Test No. 5, Magnification. Under 10X magnification no inclusions are visible but strong doubling of the back facets is noted. No separation plane is seen.

What is your interpretation? What stones can be eliminated?

What is the stone in Problem No. 3?

Practice Problem No. 4

Test No. 1, Visual Examination. Stone is pink, transparent, brilliant-cut. Appears well cut with no visible fractures, inclusions, or scratches.

Can any stone be eliminated after this test?

Test No. 2, Single or Double Refraction. Between crossed polaroids of the polariscope, the stone turns alternately light and dark as it is rotated. Viewed through the dichroscope, pink and gray colors are seen.

What gems can be eliminated after Test No. 2?

Test No. 3, Refractive Index. When placed on the refractometer, a shadow line on the scale reads 1.62. A polaroid plate rotated over the eyepiece of the refractometer causes the refractive index line to move from 1.62 to 1.64.

What does this mean? What gems on the list can now be eliminated?

Test No. 4, Specific Gravity. The stone floats in S.G. liquid 3.30 (methylene iodide), sinks rather slowly in S.G. 2.90 liquid (acetylene tetrabromide or bromoform). No separation plane (as in doublet) is seen during immersion.

Interpret this test. What gems may now be eliminated?

Test No. 5, Magnification. Under the microscope, at 30X, only a few threadlike inclusions are visible. No separation plane can be seen.

Are such inclusions typical of any gem species? What gems can be eliminated after this test?

What is the gem stone in problem No. 4?

EXPLANATION OF PROBLEM No. 2

Test No. 1, Visual Examination

Stone is light yellow, transparent, brilliant-cut, no scratches or fractures or apparent cleavages, luster appears vitreous.

Check Chart Problem 2

List of possible stones—

GEM NAME	1st TEST	2nd TEST	3rd TEST	4th TEST	5th TEST
Diamond		X	X		
Tourmaline			X	X	
Zircon			X		
Brazilianite			X	X	
Chrysoberyl			X		
Scapolite			X	X	
Sphene			X		
Spodumene			X	X	
Topaz					
Amber		X	X	X	
Sapphire			X		
Syn. Sapphire			X		
Beryl			X	X	
Hessonite		X	X		
Spessartite		X	X		
Opal		X	X	X	
Citrine			X	X	
Syn. Rutile			X		
Spinel		X	X		
Syn. Spinel		X	X		
Labradorite			X	X	
Doublets, triplets				X	
Glass		X	X		

Which should be eliminated as the result of Test 1? (Ans.) None.

Test 2, Polariscope. The stone turns alternately light and dark when rotated in the polariscope.

What is your interpretation? (Ans.) Stone is doubly refractive.

Which will you eliminate as the result of Test 2? (Ans.) Check off all singly refractive stones: diamond, amber, hessonite, spessartite, opal, spinel, synthetic spinel, glass.

Test 3, R.I. With stone on the refractometer, a reading is seen at 1.62. When polaroid is rotated over the eyepiece, and after turning the stone slightly a few times, the R.I. reading moves up and down only a little. What does this indicate? (Ans.) The stone is doubly refractive, birefringence is low.

What gems will you check off? (Ans.) Check off stones below 1.60 and above 1.65 R.I., stones with more than .015 birefringence, and all S.R. stones. This means check off all stones on list except topaz, doublets, and triplets.

Test 4, S.G. Stone is placed in heavy liquid 3.30 S.G. It sinks rapidly. No separation plane is visible. What is your interpretation? (Ans.) Stone is *over* 3.30 in S.G. It is not a doublet or triplet. Eliminate stones under 3.30 S.G., doublets and triplets. This leaves only topaz unchecked.

Test 5, Magnification. Accomplishes nothing. Test 5 is considered unnecessary.

Stone has been proven to be TOPAZ.

EXPLANATION OF PROBLEM 3

Test No. 1, Visual Examination

Stone is blue, transparent, brilliant-cut, well proportioned, very high luster, no scratches or cleavages, some pitting on girdle and facet junctions.

Check Chart Problem 3

List of possible stones—

GEM NAME	1st TEST	2nd TEST	3rd TEST	4th TEST	5th TEST
Aquamarine (beryl)			X	X	X
Apatite			X	X	X
Benitoite			X	X	X
Diamond		X			X
Doublet				X	X
Euclase			X	X	
Fluorite		X	X	X	X
Glass		X	X		X
Iolite			X	X	X
Indicolite (Tourmaline)			X	X	
Kyanite			X		X
Sapphire			X		X
Syn. Sapphire		X	X		X
Spinel			X		X
Syn. Spinel		X	X		X
Topaz			X		X
Zircon					

Interpretation. This could apply to natural, synthetic, or imitation gem stones. Worthy of attention is the pitting of facet junctions. Of the more common jewelry stones, zircon, because of almost universal heat treating, is quite brittle. It often shows such pitting. Of course, this is only an indication, not proof.

Test No. 2, Single or Double Refraction. In the polariscope, the stone turns dark four times and light four times during a revolution. Through the dichroscope two colors are seen, light blue and gray.

Interpretation. Stone is doubly refractive. The four times dark and light have no significance. All doubly refractive stones react the same way. The dichroscope reaction only confirms that stone is doubly refractive.

Stones to be eliminated? All singly refractive stones. Diamond, fluorite, glass, spinel, synthetic spinel.

Test No. 3, Refractive Index. With the stone on the refractometer, the entire scale seems shaded, no clear line or shadow edge is seen.

Interpretation. Refractive index of the stone is over 1.80, the highest that can be read on the instrument.

Stones eliminated? All stones of R.I. 1.80 or under. This includes all on the list except diamond, doublet, and zircon.

Test No. 4, Specific Gravity. When the stone is placed in 3.30 heavy liquid, it drops rapidly to the bottom. No separation plane is visible.

Interpretation. S.G. of the stone is well over 3.30. The stone is not a doublet as no separation plane is visible during immersion.

Stones eliminated? All under 3.30 in S.G. and doublet. Stones eliminated include aquamarine, apatite, euclase, fluorite, iolite, indicolite.

Test No. 5, Magnification. No inclusions or separation plane is visible under 10X. Strong doubling of the back facets seen.

Interpretation. Lack of inclusions is inconclusive. Most stones occur this way at times. Strong doubling of back facets is distinctive, indicating a stone of high birefringence and again proving its double refraction. No separation plane being visible, doublet is again eliminated.

Stones eliminated? Doublet, all singly refractive stones, and all doubly refractive stones of low birefringence. These are aquamarine, apatite, diamond, fluorite, glass, iolite, kyanite, sapphire, synthetic sapphire, spinel, synthetic spinel, and topaz.

Stones still remaining unchecked during any test—only zircon.

Correct identification, BLUE ZIRCON.

Had there been one or more additional stones unchecked, other methods would have been used to test them, perhaps the hydrostatic method for a more accurate specific gravity, higher magnification to separate synthetic from natural stones, etc.

EXPLANATION OF PROBLEM 4

Test No. 1, Visual Examination

Stone is pink, transparent, brilliant-cut, appears well cut, with no visible fractures, inclusions or scratches.

Check Chart Problem 4

List of possible stones—

GEM NAME	1st TEST	2nd TEST	3rd TEST	4th TEST	5th TEST
Diamond		X	X	X	
Tourmaline					
Zircon			X	X	
Topaz				X	
Andalusite			X		
Beryl			X	X	
Apatite			X		
Rhodochrosite			X	X	
Epidote			X	X	
Zincite			X	X	
Garnet		X	X	X	
Sapphire			X	X	
Syn. Sapphire			X	X	X
Spodumene			X		
Spinel		X	X	X	
Syn. Spinel		X	X	X	X
Opal		X	X	X	
Quartz			X	X	
Rutile			X	X	
Fluorite		X			
Proustite			X	X	
Glass		X	X		
Foil back	X				
Doublet				X	X

INTERPRETATION NEXT PAGE

Explanation. Most color tables include gems of pink and red in the same table, so the list of possibilities must include gems of both colors. Include also those stones not usually listed on individual color tables since they may be of any color — glass, foil backs, doublets. The foil back, by easy visual examination can be eliminated, but no others.

Test No. 2, Single or Double Refraction. Between crossed polaroids, stone turns alternately light and dark when rotated. Viewed through the dichroscope, colors pink and gray are seen.

Interpretation of both these tests. Stone is twice proven doubly refractive. Eliminate all singly refractive gems: diamond, all garnets, spinel, synthetic spinel, fluorite, and glass.

Test No. 3, Refractive Index. On the refractometer, a shadow line is seen at 1.62. When the polaroid plate is turned over the eyepiece, reading shifts to 1.64.

Explanation. The shifting of the R.I. reading from 1.62 to 1.64 again proves double refraction and gives the birefringence, .020.

Eliminate all singly refractive gems, same as in Test No. 2. Eliminate those with birefringence of less than .020, or very much above that amount: zircon, topaz, andalusite, beryl, apatite, rhodochrosite, epidote, sapphire, synthetic sapphire, spodumene, quartz, rutile, proustite. Eliminate gems with R.I. below 1.62 and above 1.64: zircon, beryl, apatite, rhodochrosite, epidote, zincite, sapphire, synthetic sapphire, spodumene, quartz, rutile, proustite.

Test No. 4, Specific Gravity. Stone floats in 3.30 S.G. liquid, sinks slowly in 2.90 liquid. No separation plane is seen during immersion.

Interpretation. S.G. of stone is between 2.90 and 3.30, somewhat closer to 2.90. Eliminate stones above 3.30 and below 2.90 in S.G. This includes all stones on the list except tourmaline, andalusite, apatite, spodumene, glass, foil backs, doublets. Eliminate doublets because no separation plane is seen during immersion.

Test No. 5, Magnification. Under 30X magnification only a few threadlike inclusions are visible. No separation plane is seen.

Interpretation. Threadlike inclusions, while somewhat characteristic of tourmaline, are insufficient proof of the gem's identity as they may also be seen occasionally in topaz, beryl, kornerupine, and others. Eliminate synthetic gems only. No separation plane being visible, again eliminate doublets.

The only gem stone remaining uneliminated by any test is tourmaline. If your answer to Problem No. 4 is PINK TOURMALINE, you are correct.

The most significant of the tests made was that on the refractometer. It not only gave the refractive index, but also the birefringence and proof of double refraction. The amount of birefringence, at that particular position on the scale, is characteristic of tourmaline. It will identify tourmaline with no further test necessary.

Appendix — Gem Identification Tables

Items of data left blank are not applicable or are not available.

Important gem names are in **boldface** type.

In general, all varieties of a species have the same properties. All gem species have occasional freaks which may be over or under the common range in some properties.

The opaque stones may give a poor R.I. reading or no reading at all. Heavy inclusions, such as the pyrite in lapis lazuli, may cause a wide variance in S.G.

The Refractive Index (R.I.) Table lists gem minerals numerically by lowest R.I. The first column gives the R.I. **range.**

The Specific Gravity (S.G.) Table lists gem minerals numerically by **normal** S.G., the S.G. range following.

Gem materials listed according to COLOR

Colors indicated may be light or dark.

Many stones such as chalcedony, soapstone, and calcite, may be found dyed or chemically stained any color.

Glass and plastics are not listed as they may be found any color, transparent, translucent, or opaque.

Very rare stones and very rare colors are not listed. Important and common gems are in boldface.

1st List — Transparent

TRANSPARENT
COLORLESS

Diamond
Beryl (goshenite)
Tourmaline (achroite)
Topaz
Zircon
Orthoclase
Phenacite
Apatite
Datolite
Danburite

Corundum (sapphire)
Syn. sapphire
Quartz (rock crystal)
Opal (hyalite)
Syn. spinel
Syn. rutile
Strontium titanate
Fluorite
Beryllonite
Euclase

TRANSPARENT
YELLOW, YELLOW-BROWN

Diamond
Tourmaline
Zircon
Brazilianite
Sinhalite
Chrysoberyl
Scapolite
Sphene
Spodumene
Topaz
Amber

Corundum (sapphire)
Syn. sapphire
Beryl (heliodor, golden beryl)
Garnet (hessonite, topazolite, spessartite)
Opal (fire opal, Mexican opal)
Quartz (citrine, smoky quartz)
Syn. rutile
Spinel
Syn. spinel
Labradorite

TRANSPARENT
BROWN

Diamond
Amber
Andalusite
Zircon
Opal
Obsidian
Enstatite
Fluorite
Sinhalite

Corundum (sapphire)
Garnet (hessonite, spessartite)
Quartz (smoky quartz)
Tourmaline
Topaz
Idocrase
Epidote
Kornerupine
Sphene

TRANSPARENT
GREEN

Diamond
Chrysoberyl
Andalusite
Apatite
Dioptase
Diopside
Topaz
Zircon
Peridot
Epidote
Fluorite

Corundum (sapphire)
Beryl (emerald, aquamarine)
Garnet (demantoid, uvarovite)
Spodumene (hiddenite)
Spinel
Syn. spinel
Tourmaline
Obsidian
Tektite (moldavite)
Euclase
Sphene
Kornerupine

TRANSPARENT
BLUE

Diamond
Zircon
Topaz
Benitoite
Iolite
Fluorite
Euclase
Apatite

Corundum (sapphire)
Beryl (aquamarine)
Spinel
Syn. spinel
Tourmaline (indicolite)
Quartz (siderite)
Spodumene
Kyanite

TRANSPARENT
VIOLET and PURPLE

Diamond
Tourmaline
Zircon
Spinel
Axinite
Spodumene

Corundum (sapphire)
Quartz (amethyst)
Garnet (rhodolite)
Apatite
Fluorite
Topaz

TRANSPARENT
PINK and RED

Diamond
Tourmaline (rubelite)
Zircon
Topaz
Andalusite
Beryl (morganite)
Apatite
Rhodochrosite
Epidote
Zincite

Corundum (ruby, sapphire)
Syn. ruby and sapphire
Spodumene (kunzite)
Spinel
Syn. spinel
Opal (fire opal, Mexican opal)
Quartz (rose quartz)
Rutile
Fluorite
Proustite

Garnet (almandite, pyrope, hessonite, spessartite, rhodolite)

2nd List—Transparent to Opaque

TRANSLUCENT TO OPAQUE
WHITE

Quartz (chalcedony, agate, etc.)
Jadeite
Nephrite
Grossularite
Opal
Coral
Ivory
Thomsonite

Corundum (sapphire)
Orthoclase (moonstone)
Albite
Oligoclase
Talc (steatite, **soapstone**, etc.)
Serpentine
Gypsum (satin spar)
Idocrase
Sillimanite

TRANSLUCENT TO OPAQUE
GRAY

Quartz (chalcedony, agate, etc.)
Jadeite
Nephrite
Smithsonite
Prehnite

Talc (steatite, soapstone, etc.)
Corundum (sapphire)
Serpentine
Labradorite
Sillimanite

TRANSLUCENT TO OPAQUE
BLACK

Diamond
Hematite
Opal
Jet
Spinel (ceylonite)
Obsidian

Corundum (star sapphire)
Tourmaline (schorl)
Jadeite (chloromelanite)
Nephrite
Garnet (melanite, almandite)
Quartz (morion, **black "onyx,"** pet. wood)

TRANSLUCENT TO OPAQUE
PINK and RED

Rhodochrosite
Jadeite
Amber
Scapolite
Zoisite (thulite)

Quartz (rose quartz, carnelian, jasper)
Coral
Rhodonite
Thomsonite

TRANSLUCENT TO OPAQUE
VIOLET and PURPLE

Quartz (dumortierite) (amethystine)

Diopside (violane)

TRANSLUCENT TO OPAQUE
BROWN

Quartz (sard)
Obsidian
Labradorite
Staurolite

Jadeite
Nephrite
Amber
Thomsonite

TRANSLUCENT TO OPAQUE
YELLOW-BROWN

Quartz (tiger-eye, sard, smoky quartz)
Chrysoberyl (cat's-eye, cymophane)
Amber

TRANSLUCENT TO OPAQUE
YELLOW

Jadeite
Nephrite
Smithsonite

Chrysoberyl (cat's-eye, cymophane)
Opalite
Amber
Thomsonite

TRANSLUCENT TO OPAQUE
GREEN

Jadeite
Nephrite
Turquoise
Chlorastrolite
Elaeolite
Labradorite
Malachite
Prehnite

Talc (steatite, **soapstone)**
Serpentine
Chrysoberyl (cat's-eye, cymophane)
Microcline (amazonite)
Garnet ("Transvaal jade")
Idocrase
Variscite
Thomsonite

Quartz (aventurine, chrysoprase, prase, **chrysocolla, quartz, bloodstone, buddstone)**

TRANSLUCENT TO OPAQUE
BLUE

Lapis lazuli
Sodalite
Labradorite
Jadeite
Smithsonite
Opal
Fibrolite

Quartz (chrysocolla quartz)
Diopside (violane)
Turquoise
Azurite
Lazulite
Odontolite
Corundum (star sapphire)

REFRACTIVE INDEX of GEM MATERIALS

R.I. Range	Species Name	Colors	Transp.	Biref.	System, Char.	Normal S.G.	S.G. Range
1.380 - 1.470	**OPAL**	All clrs & Clrls	tp to opq	amor	SR	2.20	1.90 - 2.30
1.434	FLUORITE	All clrs & Clrls	tp to tl	......	SR	3.15	3.05 - 3.25
1.44 - 1.55	**CROWN GLASS**	All clrs & Clrls	tp to opq	amor	SR	2.50	2.40 - 2.54
1.47 - 1.70	**PLASTIC**	All clrs & Clrls	tp to opq	amor	SR		1.18 - 1.60
1.477 - 1.497	SODALITE	Blu with white veinings	tp to opq	......	Cu SR	2.24	2.14 - 2.30
1.48 - 1.52	TEKTITE	Dull brn to grn, lt grn, yelsh-grn, blu, brn,	tp to tl	amor	SR		2.30 - 2.50
1.48 - 1.60	OBSIDIAN	Gry to blk, yelsh, redsh, blush, grnsh, white	tp to opq	amor	SR	2.45	2.30 - 2.60
1.486 - 1.658	**CALCITE**	Most clrs & clrls, may be dyed	tp to opq	.172	Hex U+	2.71	2.68 - 2.82
1.487	ANALCITE	Wht, gry, clrls	tp to tl	......	Cu SR		2.22 - 2.29
1.50	COPAL	Clrls, lt yel, lt brn	tp to tl	amor	SR	1.10	.....
1.50 ...	**LAPIS LAZULI**	Lt blu to intense blu, grnsh blu	tl to opq	......	Cu SR	2.65	2.38 - 2.95
1.50 - 1.52	ULEXITE	White	tl	.020	Mon B+		1.65 - 1.96
1.50 - 1.57	SERPENTINE	Lt & dark clrs of grn, yel, brn	tl to opq	......	Mon		2.50 - 2.80
1.50 - 1.57	**GOLDSTONE**	Golden spangles in brn glass	tl	amor	SR		2.55 - 2.70
1.502 - 1.524	CANCRINITE	Wht, gry, blu, yel, grn, redsh	tp to tl	.023	Hex U–		2.42 - 2.52
1.504 - 1.516	PETALITE	Clrls, wht, gry, redsh-wht, grnsh-wht	tp to tl	.012	Mon B+		2.39 - 2.46
1.505 - 1.506	MESOLITE	wht, clrs, gry, yelsh	tl	.001	Mon B+		2.27 - 2.29
1.508 - 1.509	LEUCITE	Wht, gry	tp to opq	.001			2.45 - 2.50
1.514 - 1.542	THOMSONITE	Wht, redsh-grn, yel, brn. Mottled or banded	tl to opq	......	Ort B+		2.30 - 2.40
1.515 - 1.717	MAGNESITE	Clrls, wht, gry, brn	tp to opq	.202	Hex U–		3.00 - 3.12
1.518 - 1.525	**MICROCLINE**	Lt yelsh-grn to blush-grn	tp to opq	.008	Tri B–	2.56	2.54 - 2.57
1.518 - 1.526	**ORTHOCLASE**	Clrls, gry, blush-gry, yel, brn	tp to tl	.005-.008	Mon B–	2.56	2.54 - 2.69
1.518 - 1.543	ALBITE	Clrls, gry, redsh, grnsh, lt yel	tp to tl	.011	Tri B+	2.63	2.57 - 2.69
1.52 - 1.53	GYPSUM	Clrls, wht, pastel shades, dyed all clrs	tl to opq	.010	Mon B–	2.328	2.314 - 2.350
1.52 - 1.57	OPERCULUM	Fine dark grn, shading to brn, sepia, brn, blk, wht	opq	......	....		2.70 - 2.77
1.525	POLLUCITE	Clrls, pinksh, yelsh	tp	......	Cu SR	2.860	2.850 - 2.905
1.529 - 1.677	WITHERITE	Yelsh, wht, gry	tp to tl	.148	Ort B–		4.25 - 4.35
1.530 - 1.685	ARAGONITE	Wht, yel, gry, grn, vio, clrls	tp to tl	.155	Ort B–	2.94	2.85 - 2.95
1.531 - 1.539	**QUARTZ cryptocrystalline**	Nearly all clrs, clrls, wht, blk	semi-tp to opq	......	Hex	2.60	2.58 - 2.65
1.532 - 1.549	OLIGOCLASE	Clrls, gry redsh, grnsh, blush	tp to tl	.010	Tri B–		2.62 - 2.67
1.532 - 1.549	ELAEOLITE	Gry, brn, grnsh, redsh	tl to opq	.005	Hex U–	2.60	2.55 - 2.65
1.534 - 1.596	IOLITE	Lt to drk blu	tp to tl	.007	Tri B–	2.63	2.57 - 2.66
1.535 - 1.537	APOPHYLITE	Wht, gry, pink, lt yel, lt grn	tp to tl	.002	Tet U+ or –	2.40	2.30 - 2.50
1.54	IVORY (dentine)	White, lt yel	opq	amor	....		1.70 - 1.98
1.54	IVORY (vegetable)	White, lt yel	opq	amor	....	..	1.38 - 1.42
1.54	**AMBER**	Yel, brn, red, wht	tp to tl	amor	SR	1.08	1.00 - 1.10
1.54 - 1.59	TALC	Gry, brn, grysh-grn, dyed any clr	tl to opq	......	Mon B–		2.70 - 2.80
1.544 - 1.553	**QUARTZ (crystalline)**	Clrls, blk & nearly all clrs	tp to opq	.009	Hex U+	2.66	2.62 - 2.68
1.544 - 1.576	SCAPOLITE	Lt clrs of yel, pink, blu, gry, clrls	tp to tl	.022	Tet U–	2.70	2.61 - 2.73
1.552 - 1.562	BERYLLONITE	Clrls, lt yel	tp	.010	Ort B–	2.85	2.80 - 3.00
1.554 - 1.628	HAMBERGITE	Grysh-wht, clrls	tp to tl	.074	Ort B+	2.347	....
1.555 - 1.572	LABRADORITE	Gry to blk, blu or grn flashes, lt yel	tp to opq	.008-.009	Tri B–	2.70	2.68 - 2.72
1.56 - 1.59	VARISCITE	Brt grn, lt grn, yel & brn in same specimen	tl to opq	......	....	2.50	2.47 - 2.54
1.560 - 1.600	**BERYL**	Nearly all clrs and clrls	tp	.005-.009	Hex U–	2.72	2.60 - 2.90
1.561 - 1.565	**BERYL Emerald (syn.)**	Grn, blush-grn	tp	.004	Hex U–		2.65 - 2.67
1.565 - 1.574	BYTOWNITE	Wht, gry, yel	tp to tl	.009	Tri B–	2.71	2.69 - 2.73
1.57 - 1.68	**FLINT GLASS**	All clrls & clrls	tp to tl	amor	SR		3.08 - 4.20
1.571 - 1.582	ANORTHITE	Wht, gry, redsh	tp to tl	.011	Tri B–	.. ..	2.73 - 2.76
1.571 - 1.614	ANHYDRITE	Vio, ppl, clrls	tp to tl	.043	Ort B+	. ...	2.89 - 2.99
1.574 - 1.588	AUGELITE	Clrls to lt yel	tp	.014	Mon B+	2.70	....
1.580 - 1.627	VIVIANITE	Blush-grn	tp to tl	.047	Mon B+	. .	2.58 - 2.68
1.586 - 1.605	HOWLITE	Wht with drk veins	opq	......	Mon B–	2.58	....
1.586 - 1.614	COLEMANITE	Wht, gry, yelsh wht	tp to tl	.028	Mon B+		2.42
1.595 - 1.633	PECTOLITE	Wht, gry	tl to opq	.038	Mon B+		2.74 - 2.88
1.597 - 1.628	BRAZILIANITE	Yel, yel-grn	tp	.021	Mon B+		2.94 - 2.98
1.60 approx.	**PEARL**	Wht, cream, rose, blk	tl to opq	......	. ...	......	2.66 - 2.76
1.60	**CORAL**	Pink to red	tl to opq	......	.. ..	2.65	2.60 - 2.70
1.60 - 1.62	TREMOLITE	Clrls, gry-grn, drk gry, blue-grn	tp to opq	.020	Mon B–	.	2.9 - 3.2
1.60 - 1.64	CHONDRODITE	Yel-brn, red, org-red	tp to tl	.040	Mon B+		3.10 - 3.20
1.60 - 1.820	RHODOCHROSITE	Red, lt red, brn, yelsh-red, orgy-red	tp to opq	.220	Hex U–		3.45 - 3.70
1.606 - 1.632	**NEPHRITE**	Grn, yel-grn, blush-grn, redsh, gry, wht	tl to opq	......	Mon B–	2.95	2.90 - 3.20
1.607 - 1.630	**TOPAZ**	Most clrs & clrls	tp	.008	Ort B+	3.53	3.40 - 3.65
1.610 - 1.650	**TURQUOISE**	Blu to blu-grn	opq	......	Tri B+	2.76	2.60 - 2.83
1.612 - 1.636	AMBLYGONITE	Yel, lt yel, clrls	tp to tl	.026	Tri B+		3.01 - 3.03
1.612 - 1.643	LAZULITE	Blue	tp to opq	.031	Mon B–	3.10	3.05 - 3.12
1.616 - 1.649	PREHNITE	Grn to yelsh-grn, gry-grn	semi-tp to tl	.033	Ort B+	2.90	2.80 - 3.00
1.618 - 1.648	**TOURMALINE**	Most clrs & clrls	tp	.020	Hex U–	3.06	3.00 - 3.15
1.62 - 1.70	JET	Black	opq	amor	SR	1.25	1.20 - 1.40
1.621 - 1.849	SMITHSONITE	Grysh-grn, blu, yel, blush-grn	tl to opq	.230	Hex U–	4.30	4.10 - 4.65
1.622 - 1.631	CELESTITE	Wht, redsh, blush	tp to tl	.009	Ort B+	.... .	3.90 - 4.00
1.626 - 1.670	DATOLITE	Clrls, pale tones of grn, red, yel, brn	tp to opq	.044	Mon B–	2.95	2.90 - 3.00
1.627 - 1.639	DANBURITE	Clrls, lt yel, lt yel-brn	tp to tl	.006	Ort B+	3.00	2.97 - 3.20
1.628 - 1.650	APATITE	Yel to grn, blush-vio, red, blu-grn, yel-grn, clrls	tp	.002-.005	Hex U–	3.18	3.10 - 3.23
1.629 - 1.648	ANDALUSITE	Brn, redsh-brn, dark yel-grn, lt red, black	tp to opq	.009-.013	Ort B+ or –		3.10 - 3.20
1.63 - 1.66	FRIEDELITE	Rose-red, org-red, clrls	tp to tl	.030	....	......	3.06 - 3.19

R.I. Range	Species Name	Colors	Transp.	Biref.	System, Char.	Normal S.G.	S.G. Range
1.636 - 1.648	BARITE	Wht, pale clrs of blu, gry, red, brn	tp to opq	.012	Ort B+	......	4.30 - 4.60
1.648 - 1.675	EUCLASE	Clrls, pale clrs of grn, blu, yel	tp	.020	Mon B+	3.10	3.05 - 3.11
1.650 - 1.693	PERIDOT	Grn, olive-grn, yelsh-grn, grnsh-yel	tp to tl	.038	Ort B+	3.30	3.25 - 3.45
1.651 - 1.668	PHENACITE	Clrls, lt yel, lt red, lt brn	tp	.015	Hex U+	2.95	2.93 - 3.00
1.653 - 1.673	ENSTATITE	Gry, grn, brn, yel, redsh-yel, redsh-brn	tp to tl	.010	Ort B+ or —	3.25	3.10 - 3.50
1.655 - 1.679	**SPODUMENE**	Clrls, grn, lt tones of red, blu, ppl, yel, grn	tp	.015	Mon B+	3.18	3.10 - 3.30
1.655 - 1.735	DIOPTASE	Emerald green	tp to opq	.053-.056	Hex U+	3.30	3.27 - 3.35
1.655 - 1.909	MALACHITE	Brt grn to blush-grn	opq	......	Mon B—	3.90	3.50 - 4.03
1.66 - 1.67	BORACITE	Wht, gry, yel, lt grn	Sub-tp to tl	......	....	......	2.9 - 3.0
1.660 - 1.680	SILLIMANITE	Lt to med blu grysh-wht to gry, blush-grn	tp to opq	.019	Ort B+	...	3.20 - 3.25
1.660 - 1.680	**JADEITE**	Brt grn, drk grn, blush-grn, red grnsh, blush, redsh, wht, blk	semi-tp to opq	......	Mon B+	3.30	3.20 - 3.40
1.662 - 1.680	KORNERUPINE	Grn, brn, clrls	tp	.012	Ort B—	3.30	3.27 - 3.40
1.663 - 1.727	DIOPSIDE	Wht, gry, drk grn, blu, pale colors of yel, grn, clrls	tp to opq	.029	Mon B+	3.29	3.20 - 3.40
1.667 - 1.705	SINHALITE	Lt brn to blk	tp	.038	Ort B—	......	3.46 - 3.52
1.668 - 1.698	AXINITE	Brn, yel, vio	tp to tl	.010	Tri B—	3.29	3.27 - 3.30
1.675 - 1.699	DIALLAGE	Lt to med grn, brn	tl	.024	Mon B+	3.30	3.20 - 3.50
1.690	RHODIZITE	Wht, grnsh, yelsh	tl	......	Cu SR	3.40	....
1.690 - 1.720	WILLEMITE	Yel, grn, brn, org	tp to tl	.030	Hex U+	4.00	3.89 - 4.18
1.698 - 1.703	ZOISITE	Gry-grn, yelsh-grn, pink to pplsh-red, mottled	tl to opq	......	Ort B+	3.30	3.25 - 3.37
1.700 - 1.731	IDOCRASE	Yel-grn, mottled darker grn, lt blu, brn, wht	tp to opq	.005	Tet U+	3.40	3.30 - 3.50
1.702 - 1.750	DIASPORE	Wht, pale colors or gry, grn, brn, yel	tl to opq	.048	Ort B+	......	3.30 - 3.50
1.703 - 1.716	HYPERSTHENE	Brnsh-grn to blk	tl to opq	.013	Ort B—	......	3.40 - 3.50
1.704 - 1.778	EPIDOTE	Yel-grn to drk brn	tp to opq	.030-.040	Mon B—	3.40	3.25 - 3.50
1.712 - 1.734	KYANITE	Lt blu, lt grn, grn, clrls	tp to opq	.012	Ort B—	......	3.56 - 3.67
1.715 - 1.730	**SPINEL** (See Gen. List for var. with higher RI)	Nearly all clrs, no clrls	tp to opq	......	Cu SR	3.60	3.50 - 3.98
1.718 - 1.723	TAAFFEITE	Pale mauve (very light lilac)	tp	.0048	Hex U—	3.61	....
1.720 - 1.848	AZURITE	Intense blue	opq	.108	Mon B+	3.80	3.75 - 3.89
1.724 - 1.734	CLINOZOISITE	Lt yel, grn, pnk, clrls	tp	.010	Mon B+	......	3.22 - 3.37
1.724 - 1.746	HODGKINSONITE	Brt pnk to rdsh-brn	tp to opq	.020	Mon B—	3.91	....
1.728 - 1.731	**SPINEL (syn.)**	All clrls & clrls	tp to opq	......	Cu SR	3.65	3.50 - 3.71
1.73 - 1.76	GROSSULARITE	Org-brn, redsh-org-brn, yelsh-grn, pink	tp to opq	......	Cu SR	3.60	3.50 - 3.75
1.730 - 1.744	RHODONITE	Blush-red, rose-red, grnsh, yelsh	tl to opq	......	Tri B+ or —	3.50	3.40 - 3.70
1.74	PERICLASE (Syn)	Clrls, lt yel	tp	......	amo CU	......	3.56 - 3.68
1.74 - 1.76	**PYROPE**	Red, brnsh-red, pplsh-red	tp	......	Cu SR	3.70	3.51 - 3.84
1.742 - 1.760	CHRYSOBERYL	Red, grn, yel-grn	tp to tl	.010	Ort B+	3.73	3.50 - 3.84
1.744 - 1.756	STAUROLITE	Brn to blk	tl to opq	......	Ort B+	......	3.65 - 3.77
1.75 - 1.77	RHODOLITE	Must be **violetish-red** color to be termed rhodolite	tp	......	Cu SR	3.84	3.74 - 3.94
1.757 - 1.804	BENITOITE	Blue, rarely clrls	tp	.047	Hex U+	3.64	3.60 - 3.69
1.759 - 1.775	**CORUNDUM** (Syn. same as natural)	Nearly all clrs and clrls	tp to opq	.008	Hex U—	4.00	3.90 - 4.10
1.780 - 1.815	ZIRCON (low)	Leaf-grn to dark brnsh-grn	tp	.005	Tet U+	4.00	3.94 - 4.10
1.79 - 1.82	SPESSARTITE	Org-red, brnsh-red, yel-brn	tp	......	Cu SR	4.15	3.80 - 4.30
1.76 - 1.83	**ALMANDITE**	Red, pplsh-red, brnsh-red	tp to opq	......	Cu SR	4.05	3.83 - 4.23
1.804 - 2.078	CERUSSITE	Wht, gry, blk, blu-grn	tp to tl	.273	Ort B—	......	6.46 - 6.57
1.84 - 1.85	UVAROVITE	Emerald green	tp	......	Cu SR	......	3.41 - 3.52
1.850 - 1.895	ANDRADITE	Grn, yel, blk, grnsh-yel	tp to opq	......	Cu SR	3.80	3.75 - 3.90
1.878 - 1.984	**ZIRCON** (high)	Clrls, lt blue, red, brnsh-red, grnsh-blu	tp	.060	Tet U+	4.70	4.20 - 4.86
1.881 - 2-053	SPHENE	Yel to brn, brn, redsh-brn, gry, brnsh-grn	tp to tl	.134	Mon B+	3.40	3.38 - 3.56
1.93	MICROLITE	Brnsh-grn, yel-brn, org-red	tp to opq	......	Cu SR	......	4.16 - 6.40
1.95 - 1.99	BAYLDONITE	Grn, yel-grn	tl to opq	.040	Mon B+	......	4.35 ......
1.985 - 2.095	CASSITERITE	Red, brn, blk, yel, gry, & near clrls	tp to opq	.097	Tet U+	......	6.80 - 7.10
1.918 - 1.934	SCHEELITE	Wht, brn, yelsh, grnsh, redsh, clrls	tp to tl	.014	Tet U+	......	5.90 - 6.10
2.013 - 2.029	ZINCITE	Yel-org to red	tl	.016	Hex U+	......	5.43 - 5.70
2.10	CHROMITE	Brn, blk	opq	......	Cu SR	4.45	4.10 - 4.90
2.304 - 2.402	WULFENITE	Org-yel, yelsh-grn, grysh-wht, org-red, gry, brn	Sub-tp to tl	.098	Tet U—	......	6.7 - 7-0
2.31 - 2.66	CROCOITE	Org-red	tl	.350	Mon B+	......	5.9 - 6.1
2.37	SPHALERITE	Brn, grn, red, yel, clrls	tp to tl	......	Cu SR	......	4.00 - 4.10
2.390-2.460	STIBIOTANTALITE	Brn, redsh yel, yel	tp to opq	.070	Ort B+	......	6.00-7.40
2.409	STRONTIUM TITANATE	Colorless	tp	......	Cu SR	5.13	....
2.417	**DIAMOND**	Clrls & lt tones of most clrs	tp to opq	......	Cu SR	3.52	3.516 - 3.525
2.493 - 2.560	ANATASE	Brn, yel, blu, blk	tp to opq	.056	Tet U—	......	3.80 - 4.04
2.553 - 2.735	BROOKITE	Brn, redsh-blk	tl to opq	.110	Ort B+	......	3.87 - 4.10
2.616 - 2.903	RUTILE	Dark red, brn, blk	tl to opq	.287	Tet U+	4.25	4.18 - 4.30
2.616 - 2.903	**RUTILE (syn.)**	Near clrls, lt clrs of yel, red, blu, grn, brn	tp to opq	.287	Tet U+	4.25	4.18 - 4.30
2.790 - 3.087	PROUSTITE	Deep red, pplsh-red	tp to tl	.297	Hex U—	......	5.57 -5.64
2.849	CUPRITE	Red to red-blk	tp to tl	......	....	......	5.85 - 6.15

amo—amorphous
B—biaxial
blu—blue
blk—black
brn—brown
clrls—colorless
Cu—cubic
dk—dark
DR—doubly refractive
gry—gray
grn—green
Hex—hexagonal
Iso—isotropic
lt—light
Mon—monoclinic
Ort—orthorhombic
opq—opaque
org—orange
pl—pale
pnk—pink
ppl—purple
rd—red
sh—ish (applied to color
SR—single refraction
syn—synthetic
Tet—tetragonal
tl—translucent
tp—transparent
Tri—triclinic
U—uniaxial
vio—violet
wht—white
yel—yellow

SPECIFIC GRAVITY of GEM MATERIAL

Specific Gravity				Refractive Index	
Normal	Range	Species Name	Hardness	Normal	Range
1.08	1.00-1.10	**AMBER**	2 - 2½	1.54	......
1.10	......	COPAL	1½-2½	1.50	......
......	1.18-1.60	**PLASTIC**	1½ - 3		1 47-1 70
1.25	1.20-1.40	JET	2½ - 4		1 62-1.70
...	1.38-1.42	IVORY (Vegetable)	2½	1.54	......
	1.65-1.96	ULEXITE	1	...	1.50-1.52
......	1.70-1.98	IVORY (Dentine)	2½	1.54	......
2.20	1.90-2.30	**OPAL**	5½-6½	...	1 43-1.47
......	2.22-2.29	ANALCITE	5 - 5½	1.487	......
2.24	2.14-2.30	SODALITE	5½ - 6		1.477-1.497
	2.27-2.29	MESOLITE	5 - 5½		1.505-1.506
	2.30-2.40	THOMSONITE	5 - 5½		1.514-1.542
......	2.30-2.50	TEKTITE	5 - 5½		1.48-1.52
2.328	2.314-2.350	GYPSUM	1½ - 2		1.520-1.530
2.347	......	HAMBERGITE	7½		1.554-1.628
2.40	2.30-2.50	APOPHYLITE	4½ - 5		1.535-1.537
	2.39-2.46	PETALITE	6 - 6½	...	1.504-1.516
	2.42	COLEMANITE	2½ - 3		1.586-1.614
......	2.42-2.52	CANCRINITE	5 - 6	...	1.502-1.524
2.45	2.30-2.60	OBSIDIAN	5 - 5½		1.48-1.60
2.50	2.47-2.54	VARISCITE	4	......	1.56-1.59
2.50	2.40-2.54	**CROWN GLASS**	5 - 5½	1.52	1.44-1.55
	2.45-2.50	LEUCITE	5½ - 6	...	1.508-1.509
......	2.50-2.80	SERPENTINE	2½ - 6	...	1.50-1.55
......	2.55-2.70	**GOLDSTONE**	5½	......	1.50-1.57
2.56	2.54-2.57	**MICROCLINE**	6 - 6½		1.518-1.525
2.56	2.54-2.69	**ORTHOCLASE**	6 - 6½		1.518-1.526
2.58	......	HOWLITE	3½	...	1.586-1.605
2.60	2.58-2.65	**QUARTZ** (Cryptocrystalline)	6½ - 7	......	1.531-1.539
2.60	2.55-2.65	ELAEOLITE	5½ - 6		1.532-1.549
......	2.62-2.67	OLIGOCLASE	6 - 7	...	1.532-1.549
2.63	2.57-2.69	ALBITE	6 - 6½		1.518-1.543
2.63	2.57-2.66	IOLITE	7 - 7½	...	1.534-1.596
	2.58-2.68	VIVIANITE	1½ - 2	......	1.580-1.627
......	2.65-2.67	**BERYL, Emerald** (Syn.)	7½ - 8		1.561-1.565
2.65	2.60-2.70	CORAL	3½	1.60	......
2.65	2.38-2.95	**LAPIS LAZULI**	5 - 5½	1 50	......
2.66	2.62-2.68	**QUARTZ (Crystalline)**	7		1.544-1.553
......	2.66-2.76	**PEARL**	2½-4½	1.60 approx.	
2.70	......	AUGELITE	5	...	1.574-1.588
2.70	2.68-2.72	LABRADORITE	6	...	1.555-1.572
2.70	2.61-2.73	SCAPOLITE	5 - 6½		1.544-1.576
......	2.70-2.77	OPERCULUM	3½ - 4		1.52-1.57
......	2.70-2.80	TALC	1 - 1½		1.54-1.59
......	2.74-2.88	PECTOLITE	5		1.595-1.633
2.71	2.69-2.73	BYTOWNITE	6 - 6½		1.565-1.574
2.71	2.69-2.82	**CALCITE**	3		1.486-1.658
2.72	2.60-2.90	**BERYL**	7½ - 8		1.560-1.600
......	2.73-2.76	ANORTHITE	6 - 6½		1.571-1.582
2.76	2.60-2.83	**TURQUOISE**	6		1.61-1.65
2.85	2.80-3.00	BERYLLONITE	5½ - 6		1.552-1.562
2.860	2.850-2.905	POLLUCITE	6½	1.525	......
2.90	2.80-3.00	PREHNITE	6 - 6½		1.616-1.649
	2.89-2.99	ANHYDRITE	3 - 3½		1.571-1.614
	2.9-3.0	BORACITE	7		1.66-1.67
	2.94-2.98	BRAZILIANITE	5½		1.597-1.628
2.94	2.85-2.95	ARAGONITE	3½ - 4		1.530-1.685
2.95	2.90-3.00	DATOLITE	5 - 5½		1.626-1.670
2.95	2.93-3.00	PHENACITE	7½ - 8		1.651-1.668
	2.90-3.20	TREMOLITE	5 - 6		1.60-1.62
2.95	2.90-3.20	**NEPHRITE**	6 - 6½		1.606-1.632
3.00	2.97-3.20	DANBURITE	7		1.627-1.639
	3.00-3.50	ODONTOLITE	5		......
	3.01-3.03	AMBLYGONITE	6		1.612-1.636
......	3.00-3.12	MAGNESITE	3½-4½		1.515-1.717
3.06	3.00-3.15	**TOURMALINE**	7 - 7½		1.618-1.648
	3.06-3.19	FRIEDELITE	4½ - 5		1.63-1.66
......	3.08-4.20	**FLINT GLASS**	5		1.57-1.68
3.10	3.05-3.11	EUCLASE	7½		1 648-1.675
3.10	3.05-3.12	LAZULITE	5 - 6		1.612-1.643
	3.10-3.20	ANDALUSITE	7½		1.629-1.648
......	3.10-3.20	CHONDRODITE	6 - 6½		1.60-1.64
3.15	3.05-3.25	FLUORITE	4	1.434	
3.18	3.10-3.30	APATITE	5		1.628-1.650
3.18	3.10-3.30	**SPODUMENE**	6½ - 7		1.655-1.679
...	3.20-3.25	SILLIMANITE	6 - 7½	...	1.66-1.68
......	3.22-3.37	CLINOZOISITE	6 - 6½		1.724-1.734
3.25	3.10-3.50	ENSTATITE	5½		1.653-1.673
3 29	3.27-3.30	AXINITE	6½ - 7		1.668-1.698
3 29	3.20-3.40	DIOPSIDE	5 - 6		1.663-1.727
3 30	3.27-3.35	DIOPTASE	5	......	1.655-1.735
3.30	3.25-3.37	ZOISITE	6 - 6½	......	1.698-1.703
3.30	3.20-3.40	**JADEITE**	6½ - 7	......	1.66-1.68
3.30	3.27-3.40	KORNERUPINE	6½		1.662-1.680
3.30	3.25-3.45	**PERIDOT**	6½ - 7	......	1.650-1.693
3 30	3.20-3.50	DIALLAGE	5 - 6	......	1.675-1.699
	3.30-3.50	DIASPORE	6½ - 7	......	1.702-1.750
3 40	......	RHODIZITE	8	1.69	......
3 40	3.30-3.50	IDOCRASE	6½		1.700-1.731
...	3.40-3.50	HYPERSTHENE	5 - 6		1.703-1.716
3.40	3.25-3.50	EPIDOTE	6 - 7	...	1.704-1.778
3 40	3.38-3.56	SPHENE	5 - 5½	......	1.881-2.053
......	3.41-3.52	UVAROVITE	7½	...	1.84-1.85
3 45		BORAZON (Boron Nitride)	10+	......	......
	3.45-3.70	RHODOCHROSITE	3½-4½	......	1.60-1.82
......	3.46-3.52	SINHALITE	6½		1.667-1.705
3.50	3.40-3.70	RHODONITE	5½-6½	...	1.730-1.744
3 52	3.516-3.525	**DIAMOND**	10	2.417	......
3.53	3.40-3.65	**TOPAZ**	8	......	1.607-1.630
...	3.56-3.67	KYANITE	5, 6, 7	...	1.712-1.734
...	3.56-3.68	PERICLASE	6	...	1 74 ......
3.60	3.50-3.75	GROSSULARITE	6½ - 7	......	1.73-1.76
3 60	3.50-3.98	**SPINEL**	8		1.715-1.730
3 61	...	TAAFFEITE	8	...	1.718-1.723
3 64	3.60-3.69	BENITOITE	6 - 6½		1.757-1.804
3.65	3.50-3.71	**SPINEL** (Syn.)	8	......	1.728-1.731
	3.65-3.77	STAUROLITE	7 - 7½	...	1.744-1.756
3 70	3.51-3.84	**PYROPE**	7¼	......	1.74-1.76
3 73	3.50-3.84	**CHRYSOBERYL**	8½	......	1.742-1.760
3 80	3.75-3.89	AZURITE	3½ - 4	......	1.720-1.848
3 80	3.75-3.90	**ANDRADITE**	6½	...	1.850-1.895
......	3.80-4.04	ANATASE	5½ - 6	....	2.493-2.560
3 84	3.74-3.94	RHODOLITE	7¼	......	1.75-1.77
..	3.87-4.10	BROOKITE	5½ - 6	......	2.553-2.735
..	3.90-4.00	CELESTITE	3 - 3½	......	1.622-1.631
3.90	3.50-4.03	MALACHITE	3½ - 4	......	1.655-1.909
3 91	......	HODGKINSONITE	4½ - 5	......	1.724-1.746
	4.00-4.10	SPHALERITE	3½ - 4	2.37	......
4.00	3.94-4.10	ZIRCON (Low)	6½	......	1.780-1.815
4.00	3.90-4.10	**CORUNDUM**	9	......	1.759-1.775
4.00	3.89-4.18	WILLEMITE	5½		1.69-1.72
4.05	3.83-4.23	**ALMANDITE**	7½	1.79	1.76-1.83
4 15	3.80-4.30	SPESSARTITE	7¼	......	1.79-1.82
4.25	4.18-4.30	**RUTILE** (Syn. same as natural	6 - 6½	......	2.616-2.903
	4.27-4.35	WITHERITE	3 - 4	......	1.529-1.677
	4.30-4.60	BARITE	2½-3½	......	1.636-1.648
	4.35 ...	BAYLDONITE	4½	...	1.95-1.99
4 30	4.10-4.65	SMITHSONITE	5½	......	1.621-1.849
4 45	4.10-4.90	CHROMITE	5½	2.10	......
4 70	4.20-4.86	**ZIRCON** (high & med.)	7½		1.875-1.984
4.80 approx.		HEMATINE	6½	......	......
	4.85-4.95	MARCASITE	6 - 6½	......	......
5.00	4.85-5.10	PYRITE	6 - 6½	......	......
5.10	4.90-5.30	**HEMATITE**	5½-6½	....	......
5.13	...	STRONTIUM TITANATE	6	2.409	......
5.50	4.16-6.40	MICROLITE	5 - 5½	......	1.93 ......
	5.43-5.70	ZINCITE	4 - 4½	...	2.013-2.029
	5.57-5.64	PROUSTITE	2 - 2½	......	2.790-3.087
	5.85-6.15	CUPRITE	3½ - 4	...	2.849 ......
	5.9-6.1	CROCOITE	2½ - 3		2.31-2.66
...	5.90-6.10	SCHEELITE	4½ - 5		1.918-1.934
6.15	6.00-6.30	COBALTITE	5½		......
...	6.00-7.40	STIBIOTANTALITE	5½		2.390-2 460
...	6.45-6.57	CERUSSITE	3 - 3½		1.804-2.078
	6.70-7.00	WULFENITE	2¾ - 3	...	2.402-2.304
..	6.80-7.10	CASSITERITE	6 - 7	...	1.985-2.095

GEM MATERIAL by HARDNESS

Gemological Table of HARDNESS

(Mohs Scale)

Hardness	Name
1	Ulexite
1 - 2	Graphite
1½	Lead (metal)
1½ - 2	Gypsum
1½ - 2	Vivianite
1½ - 2½	Copal
1½ - 3	**Plastic**
2	Tin (metal)
2 - 2½	**Amber**
2 - 2½	Proustite
2½	Finger nail
2½	Ivory
2½	Tortoise Shell
2½	Zinc (metal)
2½ - 3	Gold (metal)
2½ - 3	Silver (metal)
2½ - 3	Copper (metal)
2½ - 3	Colemanite
2½ - 3	Crocoite
2¾ - 3	Wulfenite
2½ - 3½	Barite
2½ - 4	Jet
2½ - 4½	Pearl
2½ - 6	**Serpentine**
3	**Calcite**
3 - 3½	Cerussite
3 - 3½	Celestite
3 - 3½	Anhydrite
3 - 4	Witherite
3½	**Coral**
3½	Howlite
3½ - 4	Azurite
3½ - 4	Cuprite
3½ - 4	Malachite
3½ - 4	Sphalerite
3½ - 4	Operculum
3½ - 4	Aragonite
3½ - 4½	Rhodochrosite
3½ - 4½	Magnesite
4	Fluorite
4½	Bayldonite
4 - 4½	Platinum (metal)
4 - 5	Variscite
4 - 5	Iron (metal)
4 - 4½	Zincite
4½ - 5	Friedelite
4½ - 5	Scheelite
4½ - 5	Hodgkinsonite
4½ - 5	Apophylite
4½ - 5	Palladium (metal)
5	Apatite
5	Dioptase
5	Augelite
5	Odontolite
5	**Flint Glass**
5	Pectolite
5 - 5½	Obsidian
5 - 5½	**Crown Glass**
5 - 5½	**Lapis Lazuli**
5 - 5½	Sphene
5 - 5½	Datolite
5 - 5½	Analcite
5 - 5½	Thomsonite
5 - 5½	Tektite
5 - 5½	Microlite
5 - 5½	Mesolite
5, 6, 7	Kyanite According to direction
5 - 6	Diopside
5 - 6	Lazulite
5 - 6	Diallage
5 - 6	Hypersthene
5 - 6	Cancrinite
5 - 6	Tremolite
5 - 6½	Scapolite
5½	**Goldstone**
5½	Smithsonite
5½	Brazilianite
5½	Enstatite
5½	Willemite
5½	Cobaltite
5½	Chromite
5½	Stibiotantalite
5½ - 6	**Sodalite**
5½ - 6	Beryllonite
5½ - 6	Elaeolite
5½ - 6	Anatase
5½ - 6	Brookite
5½ - 6	Leucite
5½ - 6½	**Opal**
5½ - 6½	**Hematite**
5½ - 6½	Rhodonite
6	**Turquoise**
6	Labradorite
6	Amblygonite
6	Strontium Titanate
6	Periclase (Syn.)
6 - 6½	**Nephrite**
6 - 6½	Benitoite
6 - 6½	Prehnite
6 - 6½	Bytownite
6 - 6½	Anorthite
6 - 6½	**Rutile**
6 - 6½	Orthoclase
6 - 6½	**Microcline**
6 - 6½	Albite
6 - 6½	Pyrite
6 - 6½	Marcasite
6 - 6½	Zoisite
6 - 6½	Clinozoisite
6 - 6½	Chondrodite
6 - 6½	Petalite
6 - 7	Epidote
6 - 7	Oligoclase
6 - 7	Cassiterite
6 - 7½	Sillimanite
6½	Zircon (low)
6½	Idocrase
6½	Andradite
6½	Sinhalite
6½	Hematine
6½	Pollucite
6½	Kornerupine
6½ - 7	Quartz (Cryptocrystalline)
6½ - 7	**Jadeite**
6½ - 7	**Peridot**
6½ - 7	**Spodumene**
6½ - 7	Axinite
6½ - 7	**Grossularite**
6½ - 7	Diaspore
7	**Quartz (Crystalline)**
7	Danburite
7	Boracite
7 - 7½	**Tourmaline**
7 - 7½	Iolite
7 - 7½	Staurolite
7¼	**Pyrope**
7¼	Rhodolite
7¼	Spessartite
7½	**Almandite**
7½	**Zircon (high-med.)**
7½	Andalusite
7½	Euclase
7½	Uvarovite
7½	Hambergite
7½ - 8	**Beryl**
7½ - 8	Phenacite
8	Taaffeite
8	**Spinel**
8	**Topaz**
8	Rhodizite
8½	**Chrysoberyl**
9	**Corundum**
9⅛	Tugsten Carbide (Carboloy)
9¼	Silicon Carbide (Carborundum)
9½	Boron Carbide (Norbide)
10	**Diamond**
10+	Boron Nitride (Borozon)

SPECIFIC GRAVITY AND HARDNESS OF METALS

	S.G.	Hardness		S.G.	Hardness		S.G.	Hardness
ZINC	7.14	2½	COPPER	8.89	2½-3	GOLD 14K	13.07	
TIN	7.30	2	SILVER	10.53	2½-3	GOLD 18K	15.58	
IRON	7.80	4-5	LEAD	11.01	1½	GOLD, pure	19.30	2½-3
STEEL	7.83	6-7	PALLADIUM	11.50	4½-5	PLATINUM	21.45	4-4½
NICKEL	8.90	......	GOLD 10K	11.57				

DISPERSION of Common Gem Stones, Listed Alphabetically

Stones of .017 or below, are LOW in dispersion.
Those from .018 to .023 are of MEDIUM dispersion.
Those of .024 and above, are HIGH in dispersion.

Stone	Dispersion
Apatite	.013
Almandite	.024
Benitoite	.046
Beryl	.014
Cassiterite	.071
Chrysoberyl	.015
Corundum	.018
Crown glass	.016
Danburite	.017
Datolite	.016
Demantoid	.057
Diamond	.044
Dioptase	.022
Epidote	.030
Euclase	.016
Flint glass	up to .041
Fluorite	.007
Hessonite	.028
Idocrase	.019
Iolite	.017
Orthoclase	.012
Peridot	.020
Phenacite	.015
Pollucite	.014
Pyrope	.023
Quartz	.013
Rutile (syn.)	.285 to .305 (according to direction)
Scapolite	.017
Silica glass	.010
Sillimanite	.015
Sinhalite	.017
Spessartite	.027
Sphalerite	.156
Sphene	.051
Spinel	.020
Spodumene	.017
Staurolite	.023
Strontium titanate	.198
Topaz	.014
Tourmaline	.017
Willemite	.035
Zircon	.038

DISPERSION of Common Gem Stones, Listed Numerically

Dispersion	Stone
.007	Fluorite
.010	Silica glass
.012	**Orthoclase**
.013	**Quartz**
.013	Apatite
.014	**Beryl**
.014	**Topaz**
.014	Pollucite
.015	**Chrysoberyl**
.015	Phenacite
.015	Sillimanite
.016	**Crown glass**
.016	Datolite
.016	Euclase
.017	**Tourmaline**
.017	**Spodumene**
.017	Scapolite
.017	Iolite
.017	Danburite
.017	Sinhalite
.018	**Corundum**
.019	Idocrase
.020	**Peridot**
.020	**Spinel**
.022	Dioptase
.023	**Pyrope**
.023	Staurolite
.024	Almandite
.027	Spessartite
.028	**Hessonite**
.030	Epidote
.038	**Zircon**
Up to .041	**Flint glass**
.044	**Diamond**
.046	Benitoite
.051	Sphene
.057	**Demantoid**
.071	Cassiterite
.156	Sphalerite
.198	Strontium titanate
.285 to .305	**Syn. rutile** (according to direction)

TOUGHNESS of Gem Stones, Listed **Numerically**

8 to 10 — EXCELLENT. 6 to 7½ — GOOD. 4½ to 5½ — FAIR. 1 to 4 —POOR.

10	Carbonado	5½	Zircon (not heat treated)	4½	**Microcline** (amazonite)	3½	Fluorite
8	**Jadeite**	5½	**Beryl** (emerald)	4½	Andalusite	3½	Kyanite
8	**Nephrite**	5½	**Pyrite**	4½	Lapis Lazuli	3½	Azurite
8	**Chrysoberyl**	5½	Danburite	4½	Sodalite	3½	Malachite
8	**Corundum**	5	**Zircon** (heat treated)	4½	**Serpentine**	3½	**Amber**
7½	Cassiterite	5	**Topaz**	4½	Jet	3½	Apatite
7½	**Quartz** (Crystalline)	5	Obsidian	4	Labradorite (opaque)	3½	Sphene
7½	**Diamond**	5	**Orthoclase**	4	**Opal**	3½	Axinite
7	**Quartz** (Cryptocrystalline)	5	Labradorite (transparent)	4	Albite	3½	Diopside
6½	**Beryl** (other than emerald)	5	**Rutile**	4	Beryllonite	3	**Calcite**
6½	**Tourmaline**	5	Lazulite	4	Brazilianite	3	Dioptase
6½	**Spinel**	5	Idocrase	4	Datolite	3	**Spodumene**
6½	Phenacite	5	Thomsonite	4	Willemite	3	Euclase
6	**Peridot**	5	**Turquois**	4	**Pearl**	2½	Epidote
6	Iolite	5	Smithsonite	4	Rhodonite	2½	Proustite
6	Staurolite	5	Hematite	4	Enstatite	2	Ulexite
5 to 6	**Garnet**	5	Benitoite				

TOUGHNESS of Gem Stones, Listed **Alphabetically**

Albite	3½	Danburite	5½	**Lapis lazuli**	4½	**Rutile**	5
Andalusite	4½	Diopside	3½	Lazulite	5	**Spinel**	6½
Amber	3½	Dioptase	3	**Microcline** (amazonite)	4½	Sodalite	4½
Apatite	3½	**Diamond**	7½	Malachite	3½	Serpentine	4½
Axinite	3½	Enstatite	4	**Nephrite** (jade)	8	Smithsonite	5
Azurite	3½	Epidote	2½	Obsidian	5	Sphene	3½
Benitoite	5	Euclase	3	**Orthoclase**	5	**Spodumene**	3
Beryl (Emerald)	5½	Fluorite	3½	**Opal**	4	Staurolite	6
Beryl (other than emerald)	6½	**Garnet**	5-6	**Pearl**	4	Thomsonite	5
Beryllonite	4	**Hematite**	5	**Peridot**	6	**Topaz**	5
Brazilianite	4	Idocrase	5	Phenacite	6½	**Tourmaline**	6½
Calcite	3	Iolite	6	Proustite	2½	**Turquoise**	5
Carbonado	10	**Jadeite** (Jade)	8	Pyrite	5½	Ulexite	2
Cassiterite	8	Jet	4½	**Quartz** (crystalline)	7½	Willemite	4
Chrysoberyl	8	Kyanite	3½	**Quartz** (cryptocrystalline)	7	Zircon (not heat treated)	5½
Corundum	8	Labradorite (transparent)	5	Rhodonite	4	**Zircon** (heat treated)	5
Datolite	4	Labradorite (opaque)	4				

TABLE OF PLEOCHROISM

The letters S, D, W, VW, indicate Strong, Distinct, Weak and Very Weak pleochroism. Trichroism is mentioned only if mineral usually shows a third color distinctly. Colors may vary from those shown in the table as the color of the stone varies in shade and depth of color.

ANDALUSITE (trichroic) (S) yellow—green—red.

APATITE, yellow (S to W) yellow—greenish-yellow

APATITE, blue (S) blue—yellow

AXINITE (S) (trichoic) violet—brown—green.

BENITOITE (S) dark blue—colorless.

BERYL, emerald (S) yellowish-green—blue-green

BERYL, aquamarine (W) light yellowish-green—light bluish-green.

BERYL, blue aqua (W) light blue—colorless.

BERYL, pink (W) light red-violet—light red

BERYL, yellow (W) light greenish-yellow—light blue-green.

CHRYSOBERYL (trichroic) (S) yellow, colorless—light yellow—greenish-yellow

CHRYSOBERYL, cats-eye, reddish-yellow—greenish-yellow—green.

CHRYSOBERYL, alexandrite (incandescent light) green—orange—red.

CHRYSOBERYL, alexandrite (by natural light) green—yellow—red.

CORUNDUM (syn. or natural) **ruby** (S) purplish-red—orangy-red.

CORUNDUM, sapphire, blue, (S) violetish-blue—greenish-blue.

CORUNDUM, sapphire, green (D) yellowish-green—green.

CORUNDUM, sapphire, violet (S) yellowish-red—violetish-red.

CORUNDUM, sapphire, alexandrite-like (syn.) (nat. light) bluish-green—purple.

CORUNDUM, sapphire, alexandrite-like (syn.) (incandescent light) brownish-green—purple.

DIOPTASE (W) dark green—light green.

EPIDOTE (trichroic) (S) green—yellowish-green—yellow.

IOLITE (trichroic) (S) light blue—dark blue—light yellow

KYANITE (trichroic) (D) light blue—blue—dark blue.

PERIDOT (W to D) yellow-green—green.

QUARTZ, citrine (W) light yellow—very light yellow.

QUARTZ, amethyst (W) purple—reddish purple

QUARTZ, smoky (W) brown—reddish-brown.

QUARTZ, rose (W) light pink—pink.

SPHENE (trichroic) (S) colorless—yellow—reddish-yellow.

SPODUMENE, kunzite (trichroic) colorless—pink—violet.

SPODUMENE, hiddenite (S) bluish-green—green—yellowish-green.

SPODUMENE, yellow (S) light yellow—yellow—dark yellow.

TOPAZ, (trichroic) yellow (D) bluish-yellow—yellow—orangy-yellow.

TOPAZ (trichroic) blue (D) colorless—light pink—light blue.

TOPAZ (trichroic) pink (W) colorless—light pink—pink.

TOPAZ (trichroic) pink, some stones show only - pink—yellow.

TOPAZ (trichroic) green (D) colorless—light green—blue-green.

TOURMALINE (S) red. Light red—dark red.

TOURMALINE, blue (S) light blue—dark blue.

TOURMALINE, green (S) yellowish-green—blue green or brownish-green.

TOURMALINE, brown (S) yellowish-brown—dark greenish-brown.

ZIRCON, blue (S) blue—colorless to gray.

ZIRCON, red (W) red reddish-brown.

ZIRCON, green (W) green—brownish-green.

ZIRCON, brown (W) yellowish-brown—reddish brown.

ZIRCON, yellow (W) yellow—yellowish-brown.

FALSE NAMES FOR GEMS

As used in the jewelry trade, past and present. (False names should always appear in quotes.)

"African jade"—Grossularite (garnet).
"Arizona ruby"—Pyrope (garnet).
"Arkansas diamond"—Rock crystal (quartz).
"Balas Ruby"—Pink spinel.
"Black diamond"—Hematite.
"Black moonstone"—Labradorite.
"Blue John"—Violet-blue and white banded fluorite.
"Brazilian diamond"—Rock crystal quartz.
"Brazilian emerald"—Light green tourmaline.
"Brazilian moonstone"—Scapolite.
"Brazilian ruby"—Pink topaz or tourmaline.
"Brazilian sapphire"—Light blue topaz or tourmaline.
"Brazilian tourmaline"—Andalusite.
"California jade"—Idocrase (Californite).
"California lapis"—Dumortierite quartz.
"California moonstone"—Chalcedony.
"Canadian lapis"—Sodalite.
"Cape ruby"—Pyrope (garnet).
"Colorado jade"—Microcline (amazonite).
"Crocidolite"—Tiger-eye cat's-eye (quartz).
"Crystal ware," or "Rock Crystal"—Misused for glass ware.
"Endura Emerald"—Green glass.
"Evening Emerald"—Peridot.
"False lapis"—Lazulite.
"Herkimer diamond"—Doubly terminated rock crystal quartz, from Herkimer County, N.Y.
"Hungarian Cat's-eye"—Quartz cats-eye.
"Indian Jade"—Aventurine quartz.
"Jewelers Olivine"—Demantoid (garnet).
"Korean jade"—Serpentine, talc (steatite), soapstone.
"Kandy spinel"—Almandite from Ceylon.
"Lithia emerald"—Green spodumene.
"Matara diamond"—Colorless zircon.
"Medina emerald"—Green glass.
"Mexican diamond"—Rock crystal quartz.
"Mexican onyx"—Marble (calcite).
"Mikimoto pearl"—Cultured pearl.
"Montana jet"—Obsidian.
"Occidental topaz"—Citrine quartz.
"Occidental cat's-eye"—Quartz cat's-eye.
"Oriental Amethyst"—Violet sapphire.
"Oriental Emerald"—Green sapphire.
"Pink moonstone"—Scapolite.
"Quartz topaz"—Citrine quartz.
"Rock crystal"—Misused for glass ware.
"Scientific emerald"—A triplet, or syn. sapphire.
"Scotch topaz"—Citrine quartz.
"Slaves diamond"—Colorless topaz.
"Smoky Topaz"—Citrine or smoky quartz.
"Soude emerald"—A triplet.
"Soochow jade"—Serpentine or talc (steatite or soapstone).
"Soldered emerald"—A triplet.
"Spanish topaz"—Citrine or smoky quartz.
"Spinel ruby"—Red spinel.
"Swiss lapis"—Dyed jasper.
"Synthetic Alexandrite"—Syn. Alexandrite-like sapphire.
"Synthetic amethyst"—Syn. sapphire or spinel.
"Synthetec zircon"—Syn. sapphire or spinel.
"Topaz"—Citrine quartz.
"Uralian emerald"—Demantoid (garnet).
"Water sapphire"—Iolite.
"White sapphire"—Syn. colorless sapphire.

PRONUNCIATION OF COMMON GEM AND MINERAL NAMES

Pronunciations given here are according to the best authorities available and are generally accepted by mineralogists, gemologists and geologists. Where no mineralogical or gemological authority was available, Merriam-Webster Unabridged Dictionary has been taken as authority.

ALMANDITE—AL-man-dite (never al-MAN-dite)
ALMANDINE—AL-man-dine (obsolete, use almandite)
AMBLYGONITE—am-BLIG-oh-nite
ANALCITE—an-AL-cite
APATITE—AP-a-tite
AVENTURINE—a-VEN-tchu-rin (rhymes with adventure in)
BAUXITE—BO-zite
BERYL—BEAR-il (to sound like burial with the "i" omitted. Never "burl")
BERYLLONITE—bear-IL-o-nite
BRECCIA—BRECH-ee-ah
CALCITE—KAL-site
CAIRNGORM—KAYRN-gorm
CARNELIAN—kar-NEEL-yon (in England, frequently spelled cornelian but pronounced the same)
CELESTITE—SEL-es-tite
CITRINE—SIT-reen
CHRYSOBERYL—KRIS-o-bear-il
CHRYSOLITE—KRIS-o-lite
CHRYSOPRASE—KRIS-o-prase (rhymes with praise)
CHRYSOCOLLA—kris-o-KOL-a (rhymes with Coca Cola)
CHALCEDONY—kal-SED-o-nee
CHIASTOLITE—ki-AS-toe-lite (first syllable rhymes with eye)
CROCIDOLITE—kro-SID-o-lite
CUPRITE—KOO-prite
DANBURITE—DAN-bur-ite
DEMANTOID—de-MAN-toid (rhymes with Lloyd)
ELAEOLITE—e-LEE-o-lite
GNEISS—NICE (rhymes with lice)
GOETHITE—GER-tite (first syllable rhymes with the "gert" in Gerty with most of the "r" sound left out)
GROSSULARITE—GROS-u-larite
HELIOTROPE—HEE-lee-o-trope (rhymes with rope)
HEMATITE—HEM-a-tite ("Hem" like the hem of a dress)
HYACINTH—HIGH-a-sinth
HYALITE—HIGH-a-lite
IDOCRASE—EYE-do-crase (rhymes with days)
INDICOLITE—in-DICK-o-lite
IOLITE—EYE-o-lite
KAOLIN—KAY-o-lin (rhymes with shin)
KORNERUPINE—kor-ner-OO-pin (rhymes with "you pin"
KYANITE or CYANITE—KY-a-nite
LABRADORITE—LAB-ra-do-rite
LAPIS LAZULI—LAP-is LAZH-u-lie (rhymes with pie) or LAZH-u-lee (rhymes with see)
NEPHRITE—NEF-rite (first syllable rhymes with Jeff)
NEPHELITE—NEF-uh-lite
OOLITE—OH-oh-lite (rhymes with Jo-jo-might)
OLIGOCLASE—AHL-i-go-klaze (the "i" like in sit)
PERIDOT—PAIR-i-doh (like go) or PAIR-i-dot (like tot). The first is more frequently used by gemologists.
PERIDOTITE—PAIR-i-doh-tite or pair-RID-o-tite
PHENAKITE or PHENACITE—FEN-a-kite or FEN-a-site
PLAGIOCLASE—PLAY-jo-klase
PREHNITE—PRAY-nite
PSILOMELANE—si-LOM-e-lane (the "i" like eye)
RHODOCHROSITE—ro-do-KROW-site (all "o's" rhyme with go)
RUTILE—RU-teel
SPINEL—spin-EL
SPHALERITE—SFAL-er-ite (first syllable rhymes with Cal)
SPHENE—SFEEN (rhymes with sheen)
SPODUMENE—SPOD-u-meen (usually sounds like SPODJ-u-meen)
TRAVERTINE—TRAV-er-teen
UVAROVITE—oo-VAR-oh-vite (first syllable rhymes with two)
ZINCITE—ZING-kite

BOOKS for MINERAL COLLECTORS, PROSPECTORS, GEM CUTTERS, GEM COLLECTORS

These books will be useful for their data in related fields of the earth sciences. They are written for the amateur and layman in easily understood language. You will find them at most gem and mineral dealers and book stores, or they may be ordered from: Book Department, GEMAC, P.O. Box 808, Mentone, California.

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