Gems and Gemology

SPRING 1958

See Inside Cover

Gems & Gemology

VOLUME IX SPRING 1958 NUMBER 5

IN THIS ISSUE

Richard T. Liddicoat, Jr.
Editor

Jeanne G. M. Martin
Assoc. Editor

On the Cover

An award-winning mobile jellyfish pin of diamonds and sapphires designed by Enrico Serafini, Florence, Italy. The fan-shaped body and head are mounted on trembling springs to give realistic motion. Marquise diamonds and sapphires form a body from which twisted tentacles of small diamonds stream.

Photo Courtesy Dorothy Dignam
N.W. Ayer & Son, Inc.
New York City

GEMS & GEMOLOGY is the quarterly journal of the Gemological Institute of America, an educational institution originated by jewelers for jewelers. In harmony with its position of maintaining an unbiased and uninfluenced position in the jewelry trade, no advertising is accepted. Any opinions expressed in signed articles are understood to be the views of the authors and not of the publishers. Subscription price $3.50 each four issues. Copyright 1958 by Gemological Institute of America, 11940 San Vicente Boulevard, Los Angeles 49, California, U.S.A.

Ascertaining the Nature and Extent of Damage or Inherent Flaws in Gemstones

By

G. ROBERT CROWNINGSHIELD
Director of Eastern Headquarters GIA

The Gem Trade Laboratories of the Gemological Institute of America are frequently called on to render opinions regarding the nature of cracks and flaws in many varieties of stones. Most often, the question is whether a crack is inherent, partly inherent and extended, or due to damage that occurred after the stone was polished. It is my purpose here to set forth the methods used by the staff of the Laboratories in arriving at an opinion based on careful microscopic observations.

It is common knowledge that insurance companies do not require very much information about jewelry before issuing policies and collecting premiums. Most jewelers have experienced cases where this practice has been troublesome, if not embarrassing.

Few jewelers make a detailed diagram of inherent flaws in stones they sell or appraise, other than perhaps in diamonds, since insurance companies do not demand it. Therefore, stones with inherent fractures are frequently insured that may later be mistaken for damage, causing an unnecessary and time-consuming settlement.

Let us reconstruct a hypothetical case in which an insured customer first believes he has damaged a stone. One day the insured trips and falls and believes that he has struck his star sapphire on the concrete floor. His first thought, after seeing that no bones are broken, is to inspect his star sapphire. For the first time the stone is examined carefully, perhaps with strong transmitted light. Sure enough, there is a crack! The insurance company and an adjuster are notified, and he sees the crack. The jeweler is notified. He inspects the stone with his loupe and admits that he sees a crack too. All too often the insurance company pays off, but not before considerable time and effort have been expended.

Much too frequently the supposed damage is an inherent fracture or even a characteristic fingerprint inclusion or repeated twinning, especially in star sapphires and some star rubies. This could have been proved by the proper use of a microscope and direct reflected light.

How is this done? If the flaws (cracks) come to the surface and were present at the time of last polishing, the act of polishing invariably leaves telltale evidence. This is usually in the form of polishing drag marks originating from the trailing edge of the crack. Bits of the leading edge break off and score the polished surface for varying distances from the crack. If the polishing direction happens to parallel the crack, these polishing drag marks will not be evident, of course. Instead, there may be undercutting along the crack, although in this case, especially in diamonds, there may be no visible evidence.

To observe both the polishing drag marks and the undercutting, a source of light other than the dark field of the Diamondscope or Gemolite is needed. In some cases, the ordinary overhead light attachment of the latter instrument is sufficient. With diamond, however, a more distant source of light is usually necessary. The light should be direct, not diffused. In addition, the magnifications needed are 60x and 120x, the higher power principally for diamonds. With 120x, polishing lines can frequently be detected on all facets of a diamond, but not with equal ease. Occasionally, an extraordinarily well-polished diamond may show no polishing marks even under 120x. But this same diamond with an inherent crack may show the polishing drag marks mentioned above.

Another clue that may be helpful in determining whether a crack is inherent or due to damage is the presence of foreign material within the crack. Considerable caution must be exercised here, because what may appear as a stain may be a brownish nondescript interference of light caused by air in the crack, possible in both old and new cracks. Of course, if the crack can be proved to terminate or originate in a definite fingerprint inclusion, then it must be concluded that at least part of the effect seen is inherent.

A frequent cause for concern and trouble is the fact that many colored stones, particularly flawed specimens of emerald, star sapphire and ruby, are oiled to help conceal the inherent fractures and flaws. It is shocking to learn that some merchants actually believe that this oiling is necessary in order to replace the "natural oil" of the stone lost in lapping! This fraudulent practice is engaged in quite openly; in fact, members of the staff have observed emeralds soaking in oil in sunny windows of firms that otherwise have fairly good reputations. The oils used vary considerably: from 3-in-1 penetrating oil to whale oil and even mineral oil. An oil that will "set" upon standing is preferred, since subsequent changes are slower in coming about.

Unfortunately, the presence of penetrating oils cannot always be detected, although gentle warming of a suspected stone may produce an oozing of the oil from the cracks. At the Laboratory in New York we have seen star rubies "weep" red oil and emeralds "weep" green oil. After several years, depending on the treatment the stones received meanwhile, the oil tends to dry out and cracks become more visible. For this reason, oiled stones more frequently appear in necklaces and pins than in rings.

The retailer who sells oiled stones is more than likely not aware of the oil. Hence, when the customer complains in a year or two that the stones are cracked (and she can usually recall some occasion when the piece was dropped or some other occurrence to which she can lay the blame) the jeweler goes along with the story. A microscopic examination of the surface termination of the cracks may not reveal any evidence of damage whatsoever, but instead, prove that the cracks were present at last polishing. This unfortunate situation has arisen more than once at the New York Laboratory involving firms of the highest integrity.

Most insurance policies insuring for damage (all-risk policies) do not allow for ordinary wear and tear nor for inherent weakness. The possibility that an inherent slight fracture or cleavage may extend due to wear and tear, a blow, temperature change, pressure from uneven prong tension, etc., always exists. After all, a crack in a stone can be seen only when air is allowed to enter and form a reflecting or interference plane. It is conceivable that many cracks are actually much larger than assumed, even when observed under the most favorable microscopic conditions. It requires only an extremely slight change of the thickness of the crack to allow air to enter and thus allow the crack to be seen.

Not all suspected damage is actually inherent, of course. One of the indications of actual damage is one or more chips from which fresh cracks radiate indicating a blow, cracks that do not show polishing drag marks or undercutting. Another indication is a raised flake at the point of intersection of two fresh cracks or under a prong. The raised condition indicates that it could not have left the polishing wheel in that condition. One unexpected incident that gave us a clue that the sapphires in a bracelet had been mistreated, probably by heat during manufacture, was the presence in two of the stones of "exploded" negative crystals that had pushed the surface up, much as a mushroom pushes up the ground above it.

Much disagreement about damage in diamonds originates from a lack of ability to recognize *naturals*. Some crystal surfaces actually form re-entrant angles and may appear very much as a chip. We have encountered several brilliants that have turned in their settings and thus exposed *naturals* that were originally hidden by the prongs. A study of the surface under high magnification may reveal the difference between the natural surface and the fresh cleavage or cleavage-fracture combination that is characteristic of broken diamonds. At times, it has been the experience of the Laboratory that no conclusion can be reached, since *a natural* with octohedral orientation can be confused with a cleavage nick, which, of course, has the same orientation.

A further word about the setup necessary for observing drag marks, particularly in diamonds, is in order. As expressed above, high magnification is frequently required to observe drag marks in diamond. When observing the surface of the stone in search of drag marks originating at the crack, one may see no evidence of them for much of the distance along the crack. The polishing marks may be seen to cross the crack unmodified by the crack. However, at slight zig-zags in the crack one may see drag marks. The presence of even one distinct polishing line originating at the crack is considered proof of the existence of the crack before last polishing.

Note that I have used the phrase "last polishing." This wording is used because the presence of polishing drag marks, or even some of the other clues discussed, do not necessarily prove inherence of the crack in the original crystal. We have seen cabochon sapphires in which there was evidence that the stones had been polished in their settings, whether this was an attempt to remove a setter's slip or not is unknown. Another case involved an emerald that had been broken in setting and that had been removed and repolished without the owner's permission. Since all cracks had polishing drag marks, it could not be determined which were due to recent damage and which were inherent.

May I suggest that readers practice with some star sapphires, which are rarely without some inherent fractures. One can gain much information about the nature of undercutting and polishing drag marks from these stones. Note that cabochons are polished in many directions, unlike faceted stones, particularly diamonds, in which the polishing marks are usually all in one direction. In cabochons, since the inherent cracks are almost certainly crossed by one or more of the directions, drag marks will almost certainly be seen. An exception to the rule might be stones that have been repolished in this country by certain very meticulous lapidaries who specialize in this work.

When observing star sapphires and rubies it is well to become acquainted with the appearance of repeated twinning. The re-

(Continued on page 159)

A New Look in Jade

By

MARTIN L. EHRMANN, C.G.

For centuries, man has improved gemstones by coloring, heating and, more recently, by atomic bombardment. Amethysts are changed to citrines by the heating process; agates, by a combination process of heating and dyeing, become black onyx; green beryls are transformed by heat to fine, blue aquamarines and zircons to beautiful blue and white colors.

Opal doublets are made from pieces of opal that have a great amount of fire but that are too thin for jewelry purposes. The section of opal containing most of the fire is cut into thin slices and each slice is placed on a piece of matrix, usually oval, and cemented together, creating a gem of suitable strength for mounting. Doublets and triplets are also made that simulate rubies, emeralds and garnets, by using various gem materials, glass and coloring matter.

Thus it is really not surprising that the Chinese have been experimenting with various methods of coloration to improve the sales potential of huge quantities of poor-colored jadeite. Gradually, within the past few years, artificially colored jade has appeared on the market, but no one has been certain of the method used in these processes.

When embarking on another trip to the Orient last summer, I determined to ascertain at least one popular method in use. In Hong Kong, my agent and I set out to find where the business of coloring jade was being carried out. We visited a number of factories, but they were legitimate lapidaries engaged in cutting jade. The owners indicated that they would not stoop so low as to fake the color. They believed, and rightly so, that jade sales would drop considerably if tourists became aware that jade was being artificially colored; they were most reluctant to give us any clue in our search.

However, my agent was persistent and said he would find the place. After considerable footwork, he succeeded in locating it and made an appointment for us that afternoon. But the owner was most uncooperative. I tried my best to persuade him, but he said "No!" and stuck to it. I explained that I was interested for scientific reasons only and would give him no competition, but he remained adamant. We left, and I had just about given up on this project. As we strolled along, one of the men I had just seen in the factory stopped us and told my agent, in Chinese, that he would be willing to teach me the method if I would make it worth his while. After dickering for about an hour, he agreed to accept $100 in U.S. currency. He informed us that he was the inventor of the method and was not betraying his employer by selling it to us. An appointment was made for the following day at my hotel at 8:00 A.M.

He arrived with all kinds of paraphernalia, including a small charcoal burner, various shaped bottles, tweezers, towels, wax and a grate. He set them up in the bathroom and came out talking Chinese to my agent, who immediately translated that everything was ready to go, but this gentleman wanted his money first. I objected to the idea of his apparent distrust, as I had agreed to pay after the demonstration and only if it worked.

Figure 1

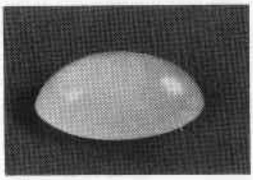


Figure 2

Figure 3

The man vehemently declared that it wasn't because he didn't trust me, but only that the method was so simple that I might not think it worth $100. So, I paid him. He was absolutely right! The method was extremely simple.

The stones had been cut encabochon from fine-quality, translucent, whitish-gray material. He heated them on a grate on top of the charcoal burner until they turned to a glossy, opaque finish. He then cooled them for about a minute and then placed them into a prepared dye solution for a short time. (Under normal circumstances, the stones are left in this dye solution for forty-eight hours.) After removal from the solution, they were rinsed in alcohol, dried on a towel and put aside. In the meantime he had heated paraffin wax very slowly in a double boiler. The stones were placed in the melting wax until they were completely covered, then removed and wiped carefully.

The basic coloring dye was an acid-base dye-stuff, such as is used in dyeing cloth. In this case, he used a yellow dye and a blue dye. The yellow dye was a #62 metanil yellow YK60, made by British Dyestuffs Corporation, Ltd. The blue dye was an acid, sky-blue B.S., made by Navy Brand First Class Dyestuffs, Ltd. These two colors were mixed together in pure alcohol, one part blue to three parts yellow, tested first for the desired color (naturally, the best color), and adjusted by adding whatever color was lacking. And that is the secret process for which I paid $100!

I was told that a salt-base dyestuff with distilled vinegar and a little cyanide would do the trick. The method of coloration would be the same as described above.

Jadeite Triplets

Another effective and widely used method of improving the color of jadeite, which results in the appearance of fine-quality Imperial jade, utilizes the following components:

a. a hollow cabochon of very fine translucent white jade about ½ millimeter in thickness all around. *(See figure 1)*

b. a cabochon of smaller size cut to fit into the hollow cabochon. *(See figure 2)*

c. a piece of flat, oval jade of the same thickness to cover the bottom. *(See figure 3)*

The center piece, the actual cabochon, is colored with a jellylike dye of the same color as the finest Imperial jade. This dye has

(Continued on page 158)

Electronic Colorimeter for Diamonds

By

ROBERT M. SHIPLEY, JR., C.G.
Major, United States Air Force, Retired

In the late 1930's, research was undertaken by the Gemological Institute of America on the color of diamonds, with the particular purpose of developing a diamond colorimeter. In 1940, the first workable instrument of this type was put together. It was essentially a split-field optical colorimeter or color comparitor of the general type then in use. Where the standard colorimeter transmitted light with a variable column of liquid for color matching, the diamond color comparitor incorporated illumination patterned as nearly as possible on that obtained when observing loose stones in a paper, and the matching field was varied by a yellow glass wedge. In operation, the diamond color comparitor permitted viewing the image of the diamond in half of the field, whereas the other half of the field was blank, and its color was varied from colorless to about a Cape yellow by the position of a wedge of yellow filter glass. The illumination was far from flat, and as a result the facets of the diamond were still pronounced, with the color varying over the observed portion of the stone. This made it quite difficult to match the other half of the field with the diamond, since there was no single block of color to match against. Another difficulty was that any attempt to match yellow against yellow is not basically the most sensitive approach. This becomes apparent from the study of *Figure 1.* The typical yellow diamond actually transmits less yellow than does a perfectly colorless diamond; only the fact that the yellow stone transmits even less of the short, or blue, end of the spectrum causes it to appear yellow to the eye. Therefore, the characteristic spectrum shift between a colorless diamond and a yellow one is in the blue and violet portion of the visible spectrum. A third defect of the optical colorimeter was that it depends too much on the physical and mental condition of the operator. The same operator, using the same stone on the same instrument might vary as much as a full color grade in the end result, even at different periods of the same day.

After World War II, the writer made desultory attempts to improve the optical colorimeter. The illumination was changed to resemble that of the integrating sphere that is standard in spectrophotometry. The flat illumination thus obtained allowed much closer matching of a cut diamond. Instead of the glass wedge, a three-color additive balancing system was employed. This method, learned from Dr. Thomas S. Curtis of color-photography fame, employs three independently variable light sources, passing through three color separation filters before falling on the illuminated object. The light-varying rheostats are calibrated, and the settings required to balance any given color are expressed in terms of lamp brightness. Thus a colorless or white object would be expressed as 100-100-100, a medium-gray object as 50-50-50, and a black object as 0-0-0. On this instrument, a typical colorless diamond reads on the order of 91-93-89. The filters used in this system were chosen to peak as nearly as practicable at the points specified by the International Commission on Illumination for the "Standard Observer"; i.e., at approximately 7000, 5460 and 4350 Angstrom Units. The resulting readings are therefore quite closely comparable to the I.C.I. coordinates that are currently used for precise naming of colors.

This version of the instrument retained the serious disadvantage of being an optical instrument, or color comparitor and therefore dependent upon the condition of the operator. The color-matching system, furthermore, was very difficult to operate until a great deal of experience had been gained. Attempts to use it sometimes resulted in complete frustration on the part of the operator.

In 1954, this instrument was shown to members of the American Gem Society, who expressed only a tepid interest. The Society, it appeared, was interested in a true colorimeter, but was looking for an instrument that would measure color electronically and that would be readily and especially usable with cut diamonds. Accordingly, the instrument was modified to illuminate the stone with white light and measure the light passed through the stone by means of photoelectric cell, with the color-separation filters interposed between the stone and the photogenerating cell. The filters employed in this colorimeter modification had transmission curves extending from approximately 7500Å to 6000Å for red, 6000Å to 5000Å for green, and 5000Å to 4000Å for blue, and with curves very nearly as specified by I.C.I. The instrument proved a very sensitive color-measuring device, and the results obtained with it were in accordance with the international standards set up by the I.C.I.

Unfortunately, the coordinates in which such results are expressed are completely unlike anything heretofore used in the diamond trade, and would require a great deal of learning to be used as diamond standards. They can be converted to a standard diamond scale, but the mathematics are cumbersome: After a series of six readings, during which the test diamond is compared against a standard for each of the three filters, the percentage transmissions must then be equated by multiplying the red-filter response by that of the green, then dividing by the square of the blue-filter response.

This colorimeter modification was shown to members of the American Gem Society, and although the author thought that the system was not unduly complicated and that its difficulties would be more than compensated by the ability to establish precise standards for all colored stones as well as diamonds, the more practical Society members disagreed quite vehemently. Accordingly, a filter was selected to combine the red- and green-filter transmissions, thus simplifying the instrument considerably. It enabled two readings of the test diamond to be equated against the standard by means of a simple computer built into the instrument. The computed results appeared in terms of the American Gem Society color scale, which had been derived from the 1940 color comparator.

The two-color instrument, now applicable solely to cut diamonds, was shown to a number of gem people, and valuable suggestions were made by Robert M. Shipley, Sr., and by Orrin Magoon, Alfred Woodill, James Donavan, Jr., Clarence van Deusen, and Jerome B. Wiss. In July of 1955, George Sloan, the newly elected president of the

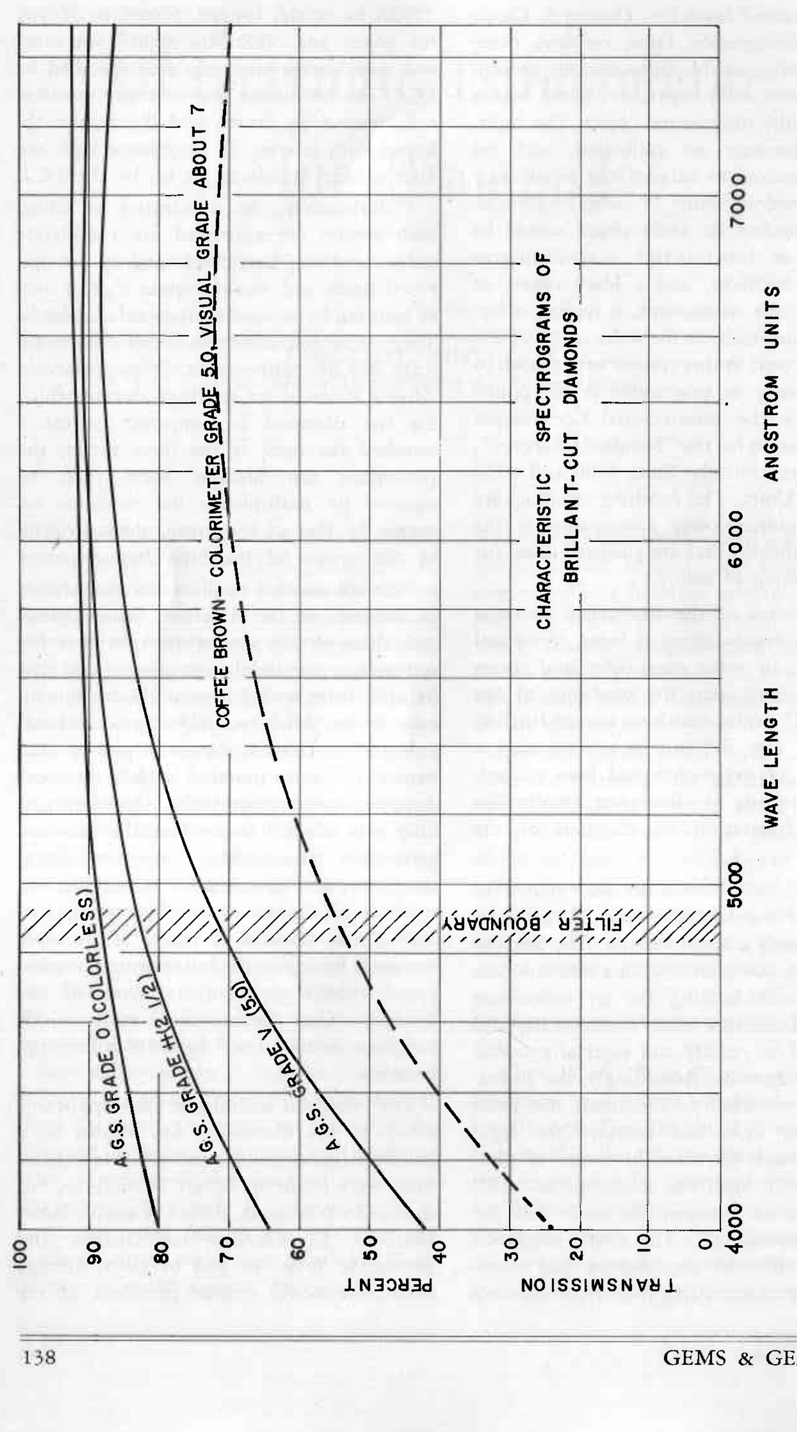


Figure 1

Spectrum curves for typical gem-quality diamonds cut as round brilliants

American Gem Society, visited the Society headquarters in Los Angeles, then made a special trip to Northern California to see this model of the colorimeter. The instrument at that time was very much a "breadboard" model, constructed of cardboard, bits of wood, and a quantity of aircraft cement. (It had the rather disturbing characteristic of occasionally bursting into flames while in operation.) Despite the crudeness of the model, Mr. Sloan was impressed with the results, and the American Gem Society subsequently advised the writer that if a suitable production pilot-model were submitted at the August, 1955, meeting of the International Committee, the Society would consider adopting it as a standard instrument and entering into an agreement to distribute it.

A metal model on the same basic principle was constructed; after testing and adjusting, it was demonstrated to the International Committee of the American Gem Society in New York in August, 1955. The International Committee expressed interest, and set up a special Colorimeter Committee to approve or disapprove the final development of the instrument. This Committee was composed of Society president George J. Sloan, C.G., William Baumgardt, Carleton G. Broer, C.G., Leo L. Kaplan and Arthur W. Muller, C.G.[1]

During this session in New York, the relatively inefficient gelatin color filters were replaced with Corning glass filters having the transmission curves shown in *Figure 2.* The filter boundary was shifted from 5000Å to approximately 4880Å, in order to compensate for a certain type of greenish-yellow diamond. These greenish-yellow stones had previously read too nearly colorless, owing to the blue content that was responsible for the greenish cast. The sharper-cutting Corning filters also had the effect of extending the scale, thus making the instrument much more sensitive.

In November, 1955, the five members of the Colorimeter Committee again met in New York to work with the new colorimeter model. These men not only traveled to New York for this express purpose, but also spent many hours in establishing a scale for the colorimeter, working especially from a quantity of stones that had been graded as master stones by the Gemological Institute. The resulting scale therefore duplicated as nearly as possible that according to which the Master Stones were graded.

At this point, consideration was given to the use of a system that had been developed to permit the grading of mounted diamonds. Because the color of the mounting greatly affects the color grade, and because of greater cost of manufacture, the Committee decided against using this design.

Following this Colorimeter Committee session, the housing of the instrument was redesigned to produce a handsomer and more easily used colorimeter, and production was started under a distribution contract with the American Gem Society. The production instrument is illustrated in *Figure 3.* In operation, the diamond is placed in the front aperture in the slide at the upper right and covered with a baffle that cuts off all light except the portion that passes through the diamond. With the blue filter in place, the slide is pulled out to place a blank standard aperture in the light path. Using the rheostats at the lower right, the meter is set at 100. The slide is pushed in to place the diamond in the light path, and the meter reading gives the percentage transmission of the diamond for the blue filter. This transmission value is set on the computer. The filter-control wheel is rotated to bring the yellow filter into the optical system, and at the same time a variable neutral-density filter superimposed on the yellow filter is adjusted to reset the meter at 100 without changing the electrical controls. (Any change in the resistance of the circuit alters the response of the photoelectric cell.) The slide is again shifted to bring the diamond into the light path, and the resulting meter reading is transferred to

---

[1] James G. Donavan, Jr. was added as a valuable sixth member of the Colorimeter Committee in September, 1956.

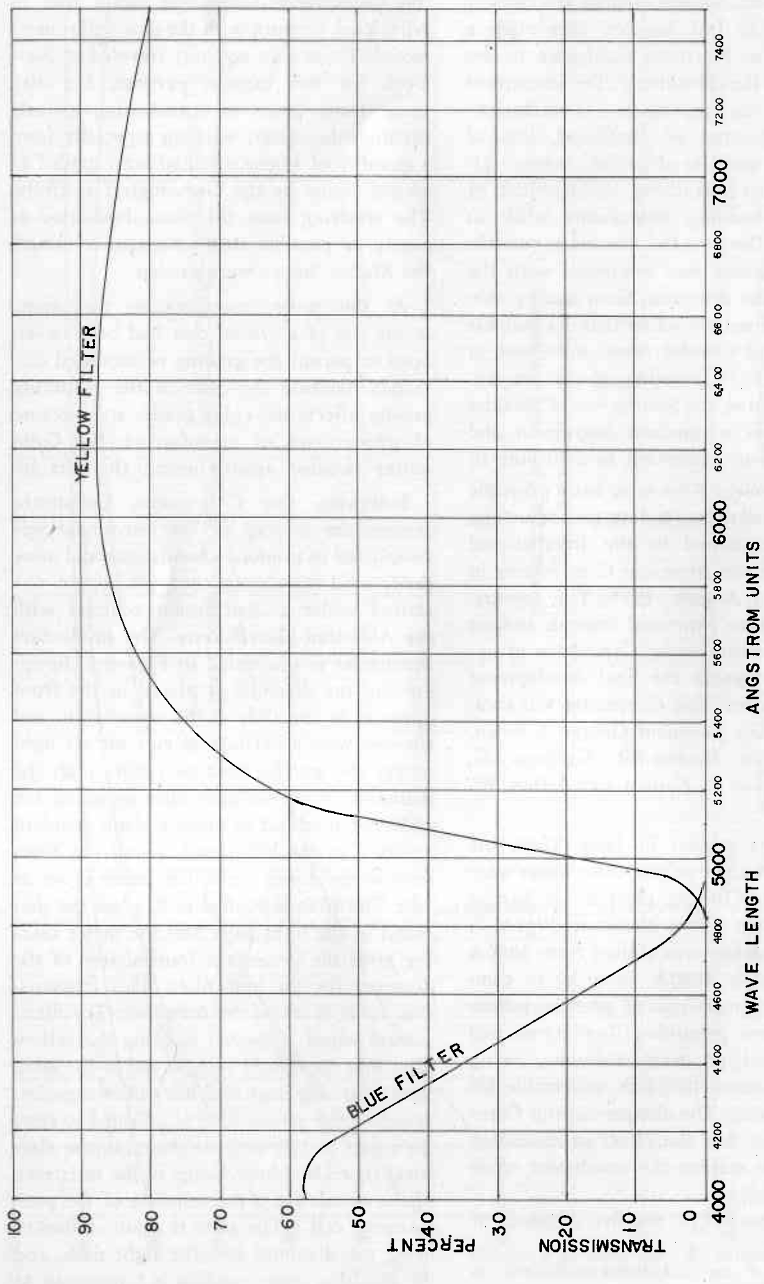


Figure 2
Spectrum curves for Corning filter-pair used in current model of Colorimeter

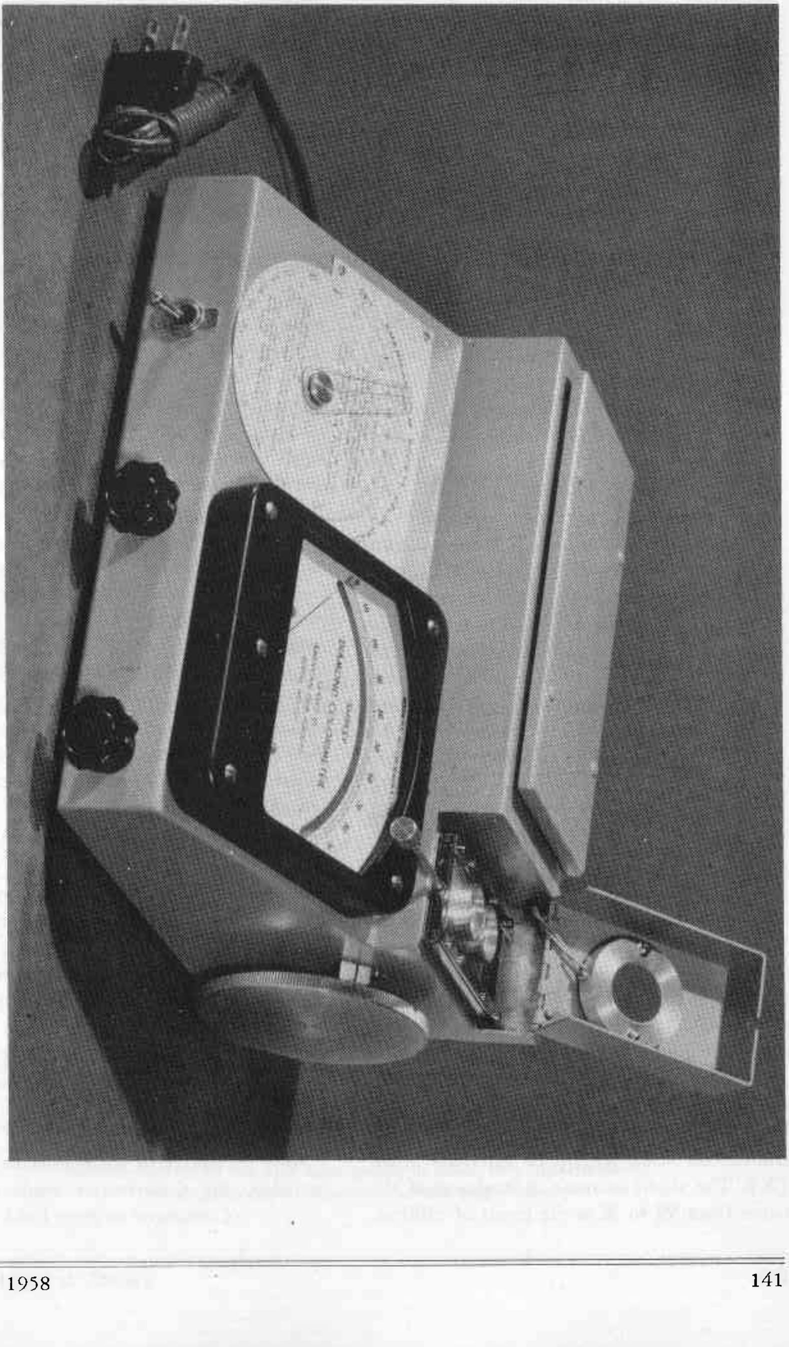


Figure 3

The Shipley Diamond Colorimeter produced for the American Gem Society the computer; this places the index on the computer over the scale of the American Gem Society color values, giving a direct reading in terms of the AGS scale. Because the highly characteristic blue-violet transmission *(Figure 1)* is the denominator of the simple fraction thus resolved, the color grade increases rapidly with the yellowness of the diamond.

The instrument is comparatively simple to use; its operation is more quickly learned than, for instance, the refractometer. Since there is no visual color matching, the psychological and physical factors affecting the accuracy of operation are materially reduced.

The scale on the American Gem Society Electronic Colorimeter is taken basically from the calibration of the wedge in the 1940 optical colorimeter. This wedge was marked from I to VI, with 0 being a point off the end of the wedge. Roman numerals were used primarily because Arabic numeral metal stamps were not available at the time. Subsequently, readings of ½ and even ¼ of a color grade were attempted. This caused an anomalous effect between 0 and I, since the wedge started at I and both 0 and ½ were, in effect, colorless. The result was that the first set of diamonds chosen for visual comparison with master stones were not graded in equal steps. This effect was further intensified when it was decided that the top color grades of 0, I and II should be much more critical (representing smaller actual color differences) than the yellower and less desirable grades. The resulting scale was approximately that from 0 to VI in *Figure 4.* When the electronic colorimeter was produced, the Colorimeter Committee saw no reason to end the scale at VI, since this point had originally been established only by the greatest thickness of the colored glass filter used in the early instrument. Accordingly, the Committee established a calibration stone at 9.4, by means of which the colorimeter scale was to be extended to 10 (X). The slight increase in steepness of the curve from VI to X is the result of calibrating the curve to this particular stone, rather than making a linear extension. The reduced steepness of the curve between 0 - II is the result of matching the colorimeter calibration to the previously established system of master-stone grading.

An anomaly occurs at about III on the scale, where the Electronic Colorimeter does not agree with the visual grading of master stones. The two scales are identical at 2½ and at 4, but a diamond that is master graded at 3 will read approximately 3½ on the Electronic Colorimeter.

As was anticipated, a number of "bugs" showed up in the first production run of colorimeters, and a few new ones appeared later. The instrument is now in its third production run, and the difficulties appear to have been ironed out satisfactorily. The most interesting problem was that certain instruments were reading both small and large diamonds properly, whereas others were grading diamonds over a carat as decidedly too yellow. It was discovered that the basis of this effect lay in the focus of the illuminating system, and that by proper adjustment of the light source and covering lenses, a large diamond could be made to read in the proper range. A pair of diamonds over one carat was incorporated in the set used for calibrating colorimeters, and critical focusing was set up as part of the calibration procedure.

The Electronic Colorimeter as now produced is not a satisfactory gauge of brown stones, for the reason illustrated by the bottom curve in *Figure 1.* The gray content of such stones results from a generally lower transmission curve, whereas the colorimeter measures only the relative balance between the lower third of the transmission spectrum and the upper two-thirds. The experienced operator suspects a brown stone when lower-than-normal readings for both the blue and the yellow filters are encountered.

Since no source of ultraviolet radiation is provided, the Colorimeter reads only the

(Continued on page 158)

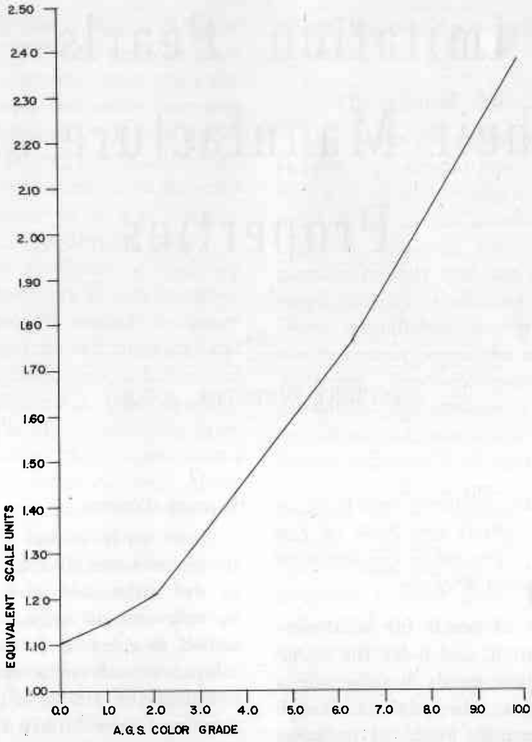


Figure 4

Response curve of the Colorimeter. AGS color grade as *abscissae;* yellow filter response divided by blue response as ordinates

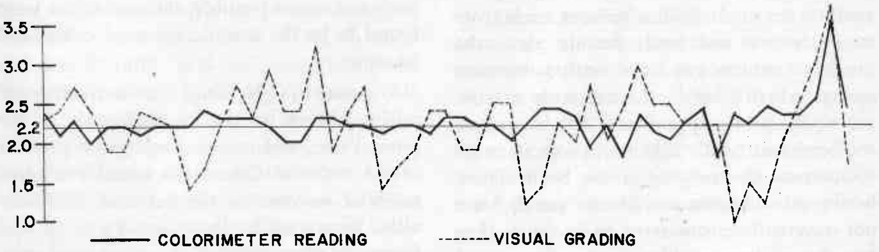


Figure 5

Field tests of diamond color grading plotted to show comparison between Colorimeter readings and visual grading by master stones. Fifty visual gradings produced eighteen errors of one-half color grade or more; fifty Colorimeter readings produced one error of this magnitude.

Imitation Pearls—Their Manufacture and Properties

By

ROBERT WEBSTER, F.G.A.

Editors note: The following article is an abstract from an entirely new book on gem materials that is at present in the course of preparation by Robert Webster.

The popularity of pearls for adornment led to their imitation, and today the manufacture of imitation pearls has become a world-wide industry. In 1656 a French rosary maker, Jonquin, produced imitation pearls at Passy, on the outskirts of Paris. Jonquin had noticed that water in which small fish had been washed contained a highly lustrous substance which, when concentrated and applied to small beads, produced a remarkably good imitation of pearls. Jonquin's pearls were small, hollow spheres made from an opalescent and easily fusible glass, the inside of which was lined with parchment sizing, which "fixed" the fish-scale essence giving the pearly appearance. The interior of the bead was finally filled with wax in order to increase the solidity of the bead. These beads, often known as "Roman pearls," are not commonly encountered today, since they have been superseded by a type using a solid glass bead, upon the outside of which is applied the pearly coating. Thus imitation pearls have at least two parts: a material producing the pearly coating and the rigid base.

Essence d'orient

Quite early it was discovered that the iridescent luster of fish scales was not part of the scales themselves, but was created by tiny crystals embedded in the skin attached to them. It is suspensions of these minute crystals in a suitable vehicle that produces the *essence d'orient,* a term that may have been derived from the possibility that the Chinese knew of the material long before Jonquin's discovery. Others at that time, a period before the art of chemical analysis was commonplace, believed the crystallites to be silver and called the material "fish silver." When careful purification and analysis became possible, the crystallites were found to be the organic chemical compound *guanine.*

Guanine ($C_5H_5ON_5$), a derivative of purin, belongs to the group known as the purin bases, and is a decomposition product of the nucleins. Guanine is actually a waste material secreted by the fish and is closely allied to uric acid. It has a density of 1.6 and forms colorless needles or lath-shaped crystals that are not decomposed by heat under 360°, are insoluble in neutral solvents, nontoxic, noncorrosive, and chemically inert.

Improvement of pearl essence

Until 1919 the manufacture of *essence*

d'orient was principally a French industry, the scales of the "bleak" *(Alburnus lucidus)* being used for the purpose. These small fish are found in the Seine and other European rivers. At one period when the French manufacture was at its height, a million francs' worth of bleak scales were exported annually from the river Thames. In 1919 it was discovered that the sardine herring caught in Norwegian waters produced a superior quality of pearl essence. A French company exploited the discovery, erected a factory in Norway, employed trained chemists, and constantly strove to improve the purity and quality of the pearl essence. Until the outbreak of World War II, the company prospered; in 1939, however, the business ceased and the process was taken to America. About 1943 experiments were made with the herring from British Columbian waters, but these were not commercially successful. Since the end of the war the Norwegian herring industry has returned to the manufacture of "fish-scale essence," and South Africa is producing its own essence from the scales of fish caught off the coasts of south and southwest Africa. In 1949 some experiments on similar lines were carried out by the Scottish herring industry, but little has been heard of this endeavor since.

The best fish scales are obtained from the herring fisheries of the Bay of Fundy, an inlet that practically divides Nova Scotia from New Brunswick in North America. Here the tides range from thirty to sixty feet and literally "boil up" the ocean floor, liberating a steady supply of fish food that attracts countless schools of herring. The fish are trapped in weirs, caught in seine nets, and loaded into crates on the scale boats, which are dories with slatted false bottoms. As the fish flop around in the crates, they lose their scales, which drop through the slats and false floor to the bottom of the boat. The scales are then scooped into baskets and hurried to the factory, which is situated in Maine, on the American side of the Bay, where, because of the numbing cold of the Fundy region, the scales arrive perfectly preserved.

The removal of the crystalloids

As soon as the scales are brought to the factory, they are put into mixers, or churns, with a suitable cleansing mixture. The movement of the churns causes the scales to rub together, releasing the tiny and delicate guanine crystals that are embedded in the tough fatty tissue attached to the fish scales. These crystalloids, as they are termed, are strained away from the scales, which are discarded. The final purification and suspension of the crystals is then made in a special solvent, which may be an ether/amyl acetate solution. This aggregate of guanine crystals in viscous liquid is then added as required to the vehicle, usually a nitrocellulose lacquer, which forms the final "paint" employed for covering the modern imitation (mock) pearls. A dyestuff is incorporated in the lacquer, if colored finishes are needed.

The bead of the modern imitation, or as they are sometimes called "simulated pearls," usually consists of a glass bead formed on an iron wire in a blowtorch flame. Subsequent treatment in sulphuric acid dissolves away the iron wire and leaves a cavity forming the string canal. The glass used is a special opalescent variety called "alabaster" (not to be confused with the massive variety of gypsum). Molded plastics, such as *Perspex* or *polystyrene,* are often used for cheap types of imitation pearls, but they are too light in weight to hang well when strung into necklaces. Further, plastic beads often show a ridge where the "flash" escapes from the junction of the halves of the mold, for these plastic beads are molded. Vegetable-ivory beads have been used as the core for imitations pearls, but they are too opaque to give the finished pearl the desired luster. A few examples have been encountered in which the bead is made of mother-of-pearl.

The beads are coated with the pearl essence, either by spraying or dipping, the

Making glass beads for imitation pearls. The wire suspended over a kerosene burner rotates slowly and drops of molten glass from the rod, held by the artisan, fall on the wire and form glass beads

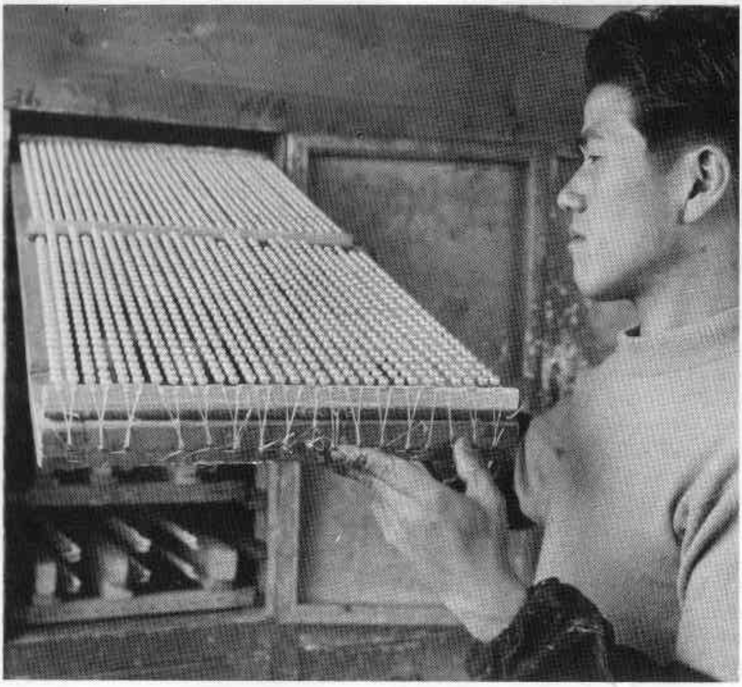
Photo Courtesy of Shell Photograph Unit

latter usually being preferable. The dipping is carried out by mounting some 500 beads on special dipping boards. The boards bristle with "toothpicks," upon which the pearls are threaded. Mounted in pairs and with the beads on the underside, the boards are gently lowered into the pearling solution until all the beads are submerged. After removal, the boards are mounted in a machine that rotates them slowly to insure an even coat while drying. The drying room needs to be air conditioned and dust free, since each dip takes from one to two and a half hours to dry. Successive coats up to ten may be put on, but usually not less than five are given so as to build up the bead to a lustrous "pearl."

The finished pearls are graded, matched and threaded on nylon or double cotton. Imitation pearls used for earrings, brooches or pendants may have only a half hole, or none at all. Such pearls are usually cemented into the settings.

Detecting imitations

Imitation pearls are easily identified by examination of the surface with a hand lens. The surface, looking like blotting paper, does not have the serrated structure of a real pearl, and at the string canal the surface of the pearl essence usually shows a wearing away from attrition with the adjacent bead. Most imitation pearls feel smooth when rubbed against the teeth, unlike the effect with natural or cultured pearls, which feel chalky or gritty. It has been noted, however, that some recent imitation pearls have been found to give this gritty feeling. A pin pressed into the surface of a coated pearl will scratch or indent it, whereas it will not do so with a nacreous pearl or with a hollow glass bead imitation. Such earlier types of imitation pearls (with a hollow glass envelope) will reveal their nature by lens examination, which shows a jagged edge to the string canal and bubbles



Bead frames, holding glass beads dipped into pearl essence, are placed in drying ovens during the manufacture of imitation pearls

Photo Courtesy of Shell Photograph Unit

in the glass envelope. If a spot of ink is placed upon the surface, it will appear doubled owing to the reflection from the internal surface of the glass shell.

Density of the pearls

The density of imitation pearls varies with the type and with the material from which the core is made. The earlier hollow glass bead type has a density usually below 1.55. With the solid bead type of coated glass, the density is usually higher than for the natural or cultured pearl, being between 2.85 and 3.18, with the higher values (over 3) being the most common. Just after the second World War, some of the glass bead imitation pearls were found to have densities of 2.3 and about 2.56. The use of these low-density glasses was considered to be due to the difficulty of obtaining the correct type of glass at this difficult time. However, recent reports suggest that such a glass (density of 2.53) is even now being used in America.

Manufactured blister pearl

An unusual type of "blister pearl" has been encountered that was constructed by covering a bead of mother-of-pearl with an envelope of essence, so thick as to be loose and not adhering to the base, and the "pearl" complete with an outer skin of glass. Black pearls have been imitated by polished spheres of hematite. Such fakes can easily be identified by the much greater density of hematite, just over 5, and by the red streak shown by the mineral when it is rubbed across a piece of white unglazed porcelain.

The pink conch pearl is simulated by coral, among other substances, but the typical "flame" markings and iridescence shown by pink conch pearl serves to identify the true from the false. A "pink pearl" made of suitably colored glass, which even had imitation "flame" markings, has been met. Examination of this piece, however, showed bubbles in the glass.

The Constituents and Nature of Matter

By

RICHARD JAHNS, Ph.D.
Professor of Geology
California Institute of Technology

Editor's Note: The next several pages are devoted to the first portion of a rather extensive exposition of the structure of matter and the nature of crystals. This study was planned for GEMS & GEMOLOGY, despite the divergence from the usual nature of the subject matter contained, because of the importance of the subject to a full understanding of the nature of gemstones and because the author has long impressed us as the most lucid in this complicated area.

Atoms and Ions

The matter that composes all physical things is made up of *atoms,* which often are referred to as the smallest units that retain their respective identities during the course of chemical reactions. These fundamental units of chemistry, in turn, are made up of still smaller units, the so-called *elementary particles,* that are associated with one another in various definite ways. Chief among them are the *proton,* the *neutron,* the *electron* and *the positron,* which can be described in terms of their masses and electrical charges, as shown in *Table 1.* These particles are so tiny that their sizes cannot be measured directly, but instead must be estimated or determined on the basis of their behavior. The diameter of the electron, for example, is approximately 4×10^{-5} Å*.

Atoms, which range in diameter from about 2Å to 6Å, can be thought of as essentially spherical domains that consist mostly of open space. Every atom has a *nucleus,* whose positive electrical charge is equivalent either to the negative charge of one electron or to even multiples of this charge. The simplest nucleus consists of one proton, and the many other known nuclei comprise one or more protons, plus a comparable, though not necessarily equal, number of neutrons. These central units have remarkably high densities of approximately 1.5×10^{-14} grams per cubic centimeter, or more than one hundred thousand billion times the density of water.

---

* The angstrom unit, Å, is one hundred-millionth of a centimeter, or 1 x 10–8 cm.

The atomic nucleus is only 1×10^{-4} to 1×10^{-5} Å in diameter, and hence takes up a very small part of the atom's total volume. Nearly all of this volume is instead traversed by one or more electrons that revolve satellitically about the nucleus, and the number of electrons in a given atom is equal to the number of protons in its nucleus. Each electron is of the same order of size as the nucleus, but has only a tiny fraction of its mass. Each moves very rapidly in all directions about the nucleus, and the average of its movements can be considered in terms of an orbit whose radius effectively defines a shell, or energy level, about the nucleus. Several essentially concentric energy-level shells, each occupied by one or more electrons, are present in all but the simplest atoms. A given atom can therefore be conveniently regarded as a cloud of electrons surrounding a nucleus that constitutes most of the atomic mass. Not only does each electron move rapidly in its orbit, but it spins as well. The protons and neutrons in the nucleus also spin like the earth, and thus each atom is a highly dynamic system.

Atoms are electrically neutral, owing to the balance of positive and negative charges between their nuclei and the surrounding clouds of electrons. This balance is upset if an atom loses or gains one or more electrons, whereby it assumes a net electrical charge and becomes an *ion*. Loss of electrons converts atoms to positively charged ions, or *cations,* and the addition of electrons forms negatively charged ions, or *anions*.

Typical derivation of ions can be represented as follows:

$$\underset{\text{(atom)}}{[\text{Nucleus} + \text{x Electrons}]} \rightarrow \underset{\text{(singly-charged cation)}}{[\text{Nucleus} + (\text{x-}1)\ \text{Electrons}]^{+}} + [\text{Electron}]^{-}$$

$$\underset{\text{(atom)}}{[\text{Nucleus} + \text{x Electrons}]} \rightarrow \underset{\text{(triply-charged cation)}}{[\text{Nucleus} + (\text{x-}3)\ \text{Electrons}]^{3+}} + 3\ [\text{Electrons}]^{-}$$

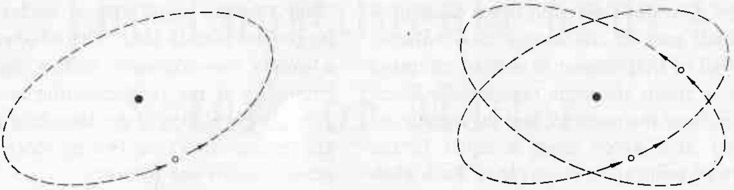
$$\underset{\text{(atom)}}{[\text{Nucleus} + \text{x Electrons}]} + 2\ [\text{Electrons}]^{-} \rightarrow \underset{\text{(doubly-charged anion)}}{[\text{Nucleus} + (\text{x}+2)\ \text{Electrons}]^{2-}}$$

Ions of this general type are very common. They contain single atomic nuclei, and can be termed *simple ions.* The effective size of a simple ion ordinarily differs significantly from that of the corresponding atom. *Complex ions,* which also are abundant in nature, are groups in which two or more kinds of atomic nuclei are present.

The Elements

An *element* can be defined as a kind of matter all of whose atoms have the same nuclear charge, or *atomic number,* and whose nuclei therefore contain the same number of *protons.* Thus all atoms of hydrogen, the simplest element, have nuclei that contain one proton whose positive electrical charge is balanced by the negative charge of a single satellitic electron, and all atoms of the element helium have nuclei that contain two protons whose total charge is balanced by that of two electrons (*Figure 1*). Similarly, the nucleus in every atom of oxygen has a charge of +8, and that in every atom of silicon has a charge of +14. However, not all atoms of a given element have the same number of *neutrons* in their nuclei; therefore, some can differ from others in mass. Alternative forms of an element that have different masses are termed *isotopes.* All known elements have two or more isotopes; some of these occur naturally, whereas others are unstable.

The chemical properties of elements are determined essentially by their atomic numbers and by the distribution and behavior of their electrons, rather than by their nuclear masses. The systematic variations of



HYDROGEN
Nucleus = 1 proton

HELIUM
Nucleus = 2 protons + 2 neutrons

Figure 1
Schematic representation of atoms of ordinary hydrogen and helium. The electrons are not in reality confined to the definite orbits shown, but instead move about the nuclei in all directions; the orbits merely convey an idea of the mean nucleus-electron distance over a period of time

these properties with atomic number are conveniently represented in the so-called *periodic system,* a common chart form of which is shown in *Figure 2.* The ninety-eight known elements in this system are readily divisible into *periods,* or horizontal rows in the chart, and the successive elements within each of these periods show orderly changes in such fundamental properties as atomic number, the number of constituent electrons, and atomic size. The entire system comprises one very short period of two elements (hydrogen and helium), two short periods of eight elements, two long periods of eighteen elements, one very long period of thirty-two elements (including the fourteen metals of the rare-earth series), and an incomplete period that includes the elements with the heaviest and most complex atomic nuclei.

The elements also are divisible into *groups,* shown as vertical columns on the chart, whose members have similar physical and chemical properties. Thus the atoms of the inert gases, or *noble gases,* of group O all have completely filled electronic shells and are so extraordinarily stable that they do not form ions and do not combine chemically with one another or with atoms of any other element.. The elements of group I-Ia, known as the *alkali metals,* or more simply as the *alkalies,* are very reactive chemically and all of them tend to combine with other elements in a grossly similar manner. Their atoms increase progressively in size with increasing atomic number, and each contains one more electron than the atom of the most closely related inert gas *(Figure 2).* Containing one less electron than the atoms of the adjacent inert gases are the atoms of the *halogens,* the elements of group VII-VIIb. They also increase progressively in size from top to bottom on the chart, but are chemically quite different from the alkalies.

The elements of group II-IIa are known as the *alkaline-earth metals,* or *alkaline earths;* those of groups IIIa, IVa, Va, VIa, VIIa, VIII and Ib are known collectively as the *transition metals.* The elements of group IIIa are sometimes excluded from the transition category, and those of groups IIb, IIIb and IVb are sometimes included. The metallic elements appear in the central and left-hand parts of the chart, and the nonmetallic elements in the right-hand part. The gradational boundary between them extends diagonally downward from the top of group III to the base of group VIb *(Figure 2).*

Atoms of any alkali metal readily lose single electrons to form ions with a single positive charge and the electronic structure of the most closely related noble-gas atom.

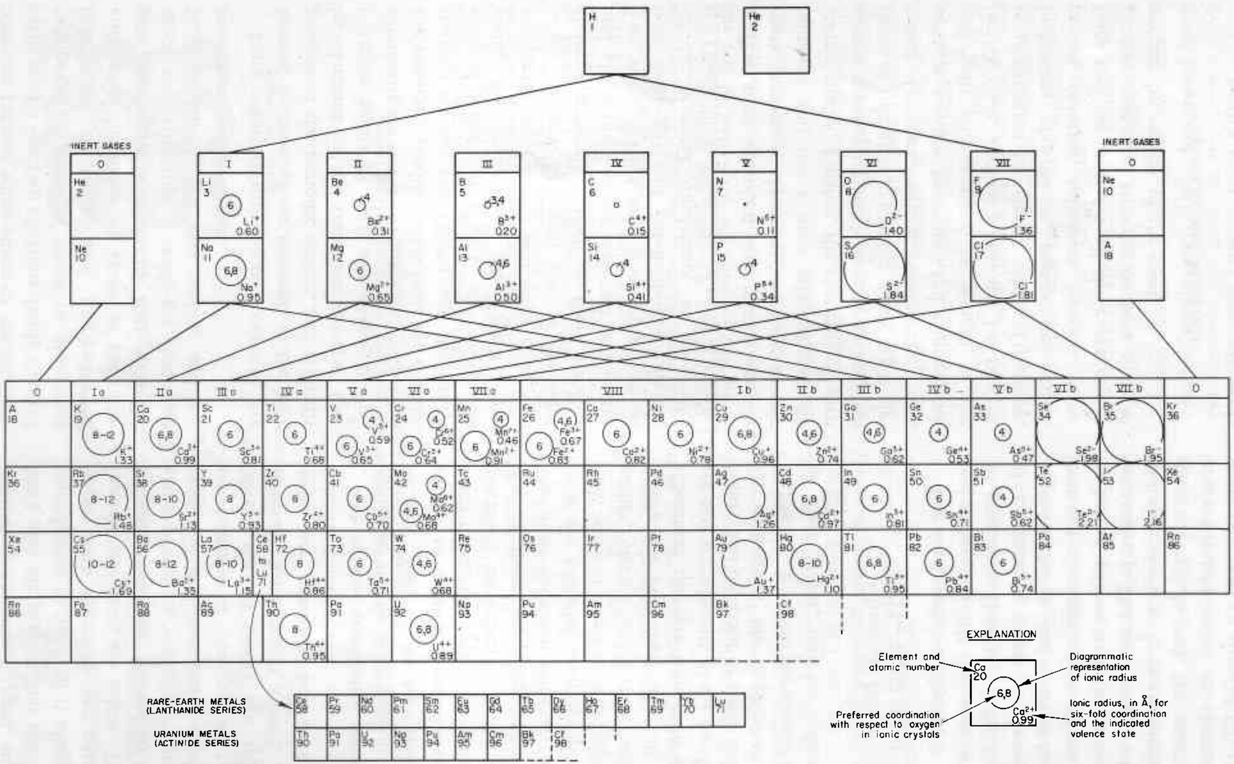


Figure 2

The periodic system of the elements

Doubly-charged cations with similar structures are formed when atoms of the alkaline-earth metals lose two electrons, triply-charged cations when atoms of boron or aluminum lose three electrons, and singly-charged anions are formed when atoms of the halogen group gain an electron. Ions with the electronic structures of noble-gas atoms are readily formed, are very stable, and are known as *noble-gas ions*.

Ions without noble-gas structure are formed by many of the elements in the long periods of the periodic system, and typically by elements in the transition groups. Two or more kinds of such *non-noble-gas ions* commonly are formed by these elements. Iron, for example, readily yields both the doubly-charged ferrous ion (Fe^{2+}) and the triply-charged ferric ion (Fe^{3+}), and manganese yields the manganous ion (Mn^{2+}), the manganic ion (Mn^{3+}) and other ions with larger charges. Different ions of the same element generally differ in their stability and are formed under different conditions. The sizes, charges and other properties of both noble-gas and non-noble-gas ions are of fundamental importance in governing the formation and behavior of solid materials.

The most abundant and mineralogically most important elements have low atomic numbers and hence have relatively simple atomic nuclei. Further, the elements of even atomic number are much more abundant than those of odd atomic number. Only eight elements (oxygen, silicon, aluminum, iron, calcium, sodium, potassium and magnesium) make up 98.6 percent by weight of the earth's crust, and an additional 1.0 percent is contributed by eleven others (titanium, hydrogen, phosphorus, manganese, sulfur, carbon, chlorine, rubidium, fluorine, strontium and barium.) Of all these, oxygen is predominant, and amounts to more than 46 percent by weight of the total.

Compounds and Minerals

The earth's crust consists preponderantly of various *compounds,* or combinations of more than one element. Some elementary substances (notably oxygen, sulfur and carbon) also are present, but their quantitative contribution to the total is almost negligible. Some earth materials are gases, some are liquids, and most are solids. Those that are homogeneous were formed by natural inorganic processes, and those whose physical properties and chemical composition either are constant or vary systematically within certain natural limits are referred to as *minerals*. Thus quartz, calcite, diamond and water are minerals, but coal, amber and volcanic glass are not.

The various combining powers of atoms, expressed in the most general way as their *valences,* lead to the formation of a wide variety of natural compounds. Many hundreds of minerals have been recognized and described, for example, although only about fifty of them are quantitatively important. The most abundant minerals in the earth's crust are silicates, aluminosilicates and oxides. Some of these, such as quartz, feldspars, garnet, olivine and zircon, are represented among the gem materials, but most of the substances that are important in gemology, are rare constituents of the earth's crust. The nature and behavior of these and other natural substances are dependent upon their structure; i.e., upon the mutual relationships of their atoms, ions or other constituent units.

Chemical Bonding
The Ionic Bond

The *ionic bond* is physically the simplest and mineralogically the most important type of interatomic binding force. It is the result of electrostatic attraction between ions of opposite charge, and hence is best developed between elements whose atoms readily lose or gain electrons to form cations or anions, respectively. The combination of sodium and chlorine atoms to form the compound $NaCl$ (the mineral halite), for example, involves the ready transfer of an electron from each atom of Na to an atom of Cl, thereby forming the noble-gas ions Na^+ and Cl^-; this

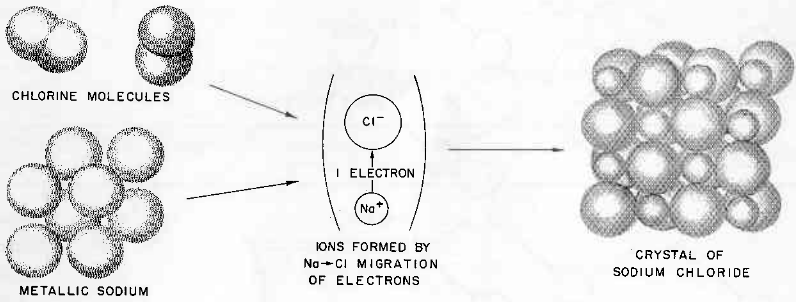


Figure 3

The reaction of chlorine molecules and a crystal of sodium to form ions that combine into a crystal of sodium chloride

is accompanied by a strong electrostatic binding of these oppositely charged ions to form crystalline NaCl *(Figure 3)*. Similarly, the compound CaF_2 (the mineral fluorite) consists of electro-statically bonded Ca^{2+} and F^- ions, both of which also are of the noble-gas type and hence very stable. The ions in such compounds can be thought of as spheres that are in essentially tangential contact with one another.

Ionic bonds generally are very strong, but their strength varies from compound to compound, depending upon the size, charge and distribution of the constituent ions, as well as upon other factors. The superior hardness and mechanical strength of many minerals is attributable to the dominance of strong ionic bonding within them.

The Covalent Bond

The covalent bond, also of great importance in minerals, arises from the *sharing* of electrons between atoms. Each molecule of chlorine shown in *Figure 3*, for example, comprises two Cl atoms that share two of their electrons; each of the two contribute an electron on a part-time basis, but also gains an electron on a similar basis and thereby achieves the very stable electronic configuration of the most closely related noble gas, argon (*Figure 2*). Thanks to this double duty of the shared electrons, the electron clouds of the two atoms interpenetrate to a significant degree *(Figure 3)*, and each atom can be regarded as a deformed sphere that is elongated in the direction of the other atom. Once the two atoms of chlorine are bound together, all possible electron sharing is completed and no further covalent bonding of these individuals to additional atoms is possible. The atom pair constitutes a *molecule,* the smallest discrete unit that exhibits the properties of the substance, and it can be bound to other atoms or molecules only by kinds of forces that are not covalent.

Covalent bonds can be very strong, but they show even greater variation in strength than ionic bonds. Unlike ionic bonds, they are specifically directed in space, so that they exercize a fundamental control over the positioning of the atoms that they bind together. The structure of a diamond crystal (*Figure 10*)**, for example, results from the definite orientation of covalent bonds between adjacent carbon atoms. Four bonds from each of these atoms are disposed tetrahedrally; i.e., they can be visualized as extending toward the vertices of an enclosing regular tetrahedron. This directional property restricts the atoms in the diamond cry-

---

** The figure references in this article, of necessity, are not in numerical sequence.

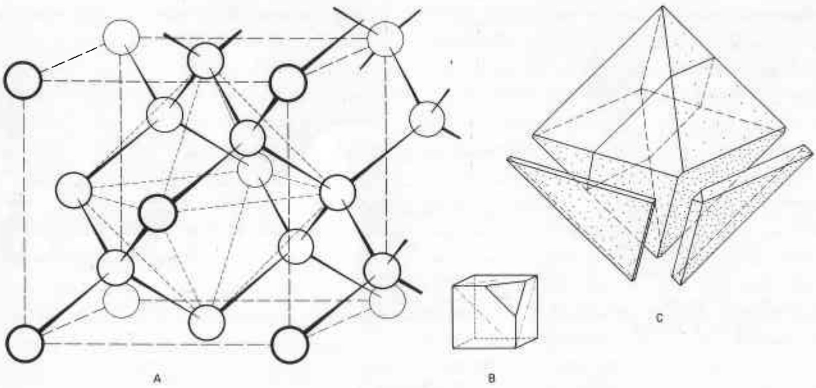


Figure 10

The structure, crystal form and cleavage of diamond. In the lattice diagram (A) the carbon atoms nearest the observer are shown as the darkest circles, and those farthest away as the lightest circles. Bond directions not parallel to the plane of the paper are tapered in a direction away from the observer. Note how the octahedral cleavage of this mineral (B and C), which is difficult but perfect, involves the breaking of strong covalent bonds between layerlike concentrations of carbon atoms

stal to an arrangement that includes much open space; if the bonding were ionic instead of covalent, a more closely packed structure and an even more dense mineral would be the likely result.

Other Types of Bonding

The bonds in most minerals are neither entirely ionic nor entirely covalent, but instead are intermediate, or *hybrid,* in nature. Some can be regarded as ionic with partial covalent character; others as covalent with partial ionic character, and all gradations between the two "pure" types of bonding can be expected. One can consider the electronic structure of such hybrid bond types as shifting rapidly, or *resonating,* between purely ionic and purely covalent arrangements.

The complex $[SiO_4]^{4-}$ ion, the fundamental building block of the silicate minerals and natural glasses, is bound together by forces that are slightly more covalent than ionic. The oxygen atoms are tetrahedrally grouped, or *coordinated,* about the silicon atom (*Figure 6*), whose bonds thus are directed like those of the carbon atoms in a diamond crystal. The relative sizes of the Si and O atoms (or ions) are almost ideal for the conservation of space, as they permit an extremely close packing within each tetrahedral group. The bonding is very strong, and the $[SiO_4]^{4-}$ ion is extraordinarily stable.

Other "pure" types of bonding include the *hydrogen bond,* which is important in structure of water, the *metallic bond,* which is dominant in metals and some sulfides, and the very weak *residual bond,* which is most important in organic compounds. These need not be considered here, since they have very limited significance in connection with most gem materials; their major characteristics, however, are summarized in *Table II.*

The States of Aggregation

The Gaseous State

Substances in the gaseous state ordinarily consist of individual molecules or relatively small molecular groups that are not bound to one another and hence can move about rather freely and independently in response to the thermal agitation that exists at all temperatures above absolute zero. A body of gas has neither definite shape nor definite size, and merely assumes the shape of the

TABLE I

Mass and Electrical Charge of the Principal Elementary Particles of Matter

Particle	Mass In Units of The Atomic-Weight Scale*	Electrical Charge †
Proton	1.00758	+1
Neutron	1.00897	0
Electron	0.000548	−1
Positron††	0.000548	+1

*This scale is based on a mass of 16.00000 for the common isotope of the oxygen atom, O^{16}.

†Referred to the charge on the electron as magnitude 1.

††Ordinarily neglected in simple considerations of atomic structure.

TABLE II

Characteristics of Five Major Types of Bonding

Bond Type	Nature Of Attraction	Intrinsic Directional Characteristics	Strength	Typical Substances In Which It Is Significant
Ionic	Electrostatic	Not directed in space	Strong variable	Glasses; silicates and other metal-oxygen compounds
Covalent	Shared electrons	Directed in space and limited in number	Strong, highly variable	Glasses; silicates, carbonates, sulfides; many nonmetallic elements and organic compounds
Hydrogen	Electrostatic	Directed according to covalent bonding in the participating molecules	Moderately strong	Water, hydrogen fluoride, some organic compounds
Metallic	Electrostatic	Not directed in space	Highly variable	Metals, some sulfides
Residual	Electrostatic	Not directed in space	Very weak	Noble gases, halogens, many organic compounds

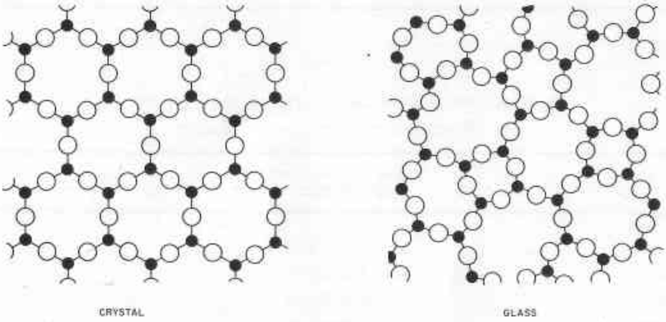


Figure 4

Two-dimensional representation of structures for a compound whose chemical formula is A_2X_3. Crystal form, with high degree of geometric order, is shown at left, and glass of same composition but with much shorter ranges of geometric order is shown at right.
same composition but with much shorter ranges of geometric order is shownat right.
Positions of A atoms are marked by solid circles, and positions of X atoms by larger open circles. ***After W. H. Zachariasen***

container that encloses it. At room temperature and normal atmospheric pressure, the average distance between the molecules of a gas is greater than the diameter of the molecules by a factor of approximately ten, so that these particles have relatively few collisions per unit distance traveled.

With a progressive rise in confining pressure, a gas is compressed and its density is increased as its constituent molecules are forced closer and closer together. They are free to move over smaller and smaller distances between collisions, which thus become increasingly frequent. As the molecules bounce about in the immediate vicinity of their neighbors for longer and longer periods of time under the influence of very high rising pressure, there is a growing tendency toward binding together, or *association,* into mobile groups, or clusters, that resemble the structural arrangements in typical liquids. Each group undergoes many changes of form as bonds between molecules are broken and new ones are established, but there are net increases in size and number of the groups as the pressure is raised to still higher levels.

The Liquid State

The liquid state is a condensed one in which the cohesive forces prohibit much,

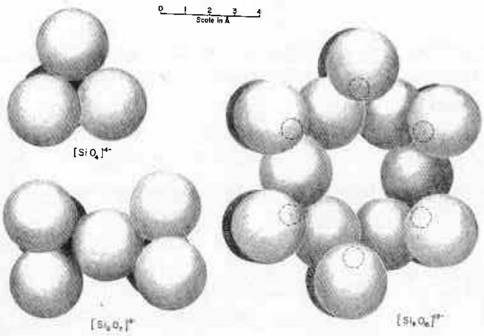


Figure 6

An SiO_4 group and two linkages of such groups formed by sharing of oxygen ions

but not all, of the gross internal movements that characterize a gas. Viewed in ordinary terms, a liquid does not have a definite shape, but does occupy a definite volume under a given set of physical conditions. It has no strength and flows in response to applied forces, although the *rate* of flow can vary tremendously from one liquid to another.

In structural terms, a liquid is a close-packed assemblage of atoms, ions, molecules, or combinations thereof, in which there is much small-scale geometric regularity akin to that developed on a vastly larger scale in crystalline solids. There is also, however, a substantial amount of structural disorder that results chiefly from thermal movements of those constituents that are not bound together in larger and less mobile groups. Too, the larger groups themselves continually change in shape, size and orientation as new bonds are formed and older ones are broken. With a decrease in the percentage of unbonded constituents in a given liquid its internal mobility also decreases and its viscosity is thereby increased.

Increases in confining pressure applied to a liquid tend to increase its viscosity, and ultimately can result in its freezing to a crystalline solid. Increases in temperature decrease its viscosity and favor the separation of gas (vapor), owing to intensified thermal agitation of its constituents and attendant net increases in the breaking of bonds among them.

The Solid State

Most substances in the solid state form *crystals,* in which the constituent atoms, ions or molecules are arranged in specific geometric patterns. Thermal energy causes them to vibrate over very short distances about specific mean positions in the three-dimensional structure of a given crystal, and they are held in these positions by relatively strong binding forces. Breaking and remaking of bonds does take place and some of the constituents do change their positions from time to time, but in general these are minor considerations at temperatures well below the melting point of the substances involved.

At higher temperatures the thermal agitation increases to the extent where it provokes many changes of position, and at still higher temperatures there is a significant *net* breaking of bonds in the structure. The crystal thereby melts, generally over an exceedingly small but nonetheless real range in temperature, and it disintegrates into a liquid that may contain numerous scraps of the original crystal structure. These masses of "wreckage" ordinarily are few atomic diameters in size, but some can be much larger. They account for a certain amount of short-range geometric regularity in the liquid, but tend to be distributed and oriented at random.

Some solid substances, such as opal and obsidian, have been regarded as noncrystalline, or amorphous, on the basis of their general appearance or behavior. They have been distinguished from viscous fluids because they apparently require application of a definite threshold force before they yield to stress by flowage. However, many of them actually do yield as fluids, but so very slowly that the process is difficult to recognize and measure. Obsidian or any other glass, for example, is most appropriately regarded as a highly viscous supercooled liquid in which there is a very large percentage of bonding but a degree of geometric order significantly less than that in a crystal *(Figure 4).*

Other substances that formerly were designated as amorphous solids are now known to be *cryptocrystalline.* Many of these are aggregates of extremely small crystal units, in some instances not much larger than the scraps of pattern in liquids. Others appear to consist of both crystal units and interstitial material with a liquidlike structure, so that they represent an intimate combination, or blending, of the liquid and solid states.

(to be continued)
(in Summer 1958)

(Continued from page 142)

body color of a fluorescent diamond. For years there has been speculation as to the possible maximum effect of fluorescence on grading, and the Colorimeter appears to give the answer: Diamonds have been observed that read two full color grades poorer on the Colorimeter than their visual appearance in unimpeded north daylight (containing ultraviolet). These stones in ultraviolet-deficient artificial light visually match the Colorimeter grade!

In order to check on the effectiveness of the Colorimeters in normal use, a set of three stones of varying color are currently being circulated among Colorimeter owners, with the owners' readings sent in for comparison. To date, these field-test stones have been run on 51 of the 66 instruments in service. The compiled results show a very gratifying correspondence among the Colorimeters. The average variation is less than 1/5 of color grade, or many times the accuracy for visual grading in comparison to master stones, as shown by similar field tests of a normal range of colorless to yellow stones. The only gross errors have been proved to be the result of incorrect operation rather than of defective Colorimeters. Several instruments that were suspected of being out of calibration have been given a critical laboratory check, and every one was found to be accurate. This is not to say that there have not been mechanical and electrical breakdowns, but only that when the instrument is functioning, the only gross errors have been traced to incorrect operation. This includes Colorimeters that have been in service for over two years.

The color differences that must be resolved to grade diamonds are very much smaller than the color differences that are considered significant in most applications of colorimetry. Therefore, an instrument to measure diamond colors must be capable of a much higher order of sensitivity than is required for the electronic colorimeters used in chemistry, medicine, and the like. The American Gem Society Colorimeter, therefore, is an extremely sensitive and accurate instrument. With it, color differences that are much too fine to be consistently distinguished by eye are sharply resolved. The Colorimeter has the additional advantage that it standardizes diamond color grading throughout the country with a dependability that is impossible by other means. Not only does it measure accurately very fine color differences in diamonds, but it also reads the same as other colorimeters in service. This permits a high degree of standardization of diamond colors among the owners of the instruments.

(Continued from page 135)

the consistency of mint jelly and looks like it. The center piece is then placed into the hollow one, and the bottom piece glued on and repolished to make a perfect fit. When unset, such triplets can be recognized easily by the seam on the bottom of the cabochon. Otherwise, the result is perfect, giving the appearance of the finest quality, most expensive jadeite.

This beautiful appearance led many unscrupulous manufacturers to cash in quickly. After being mounted in the Chinese fashion (i.e., with a plate covering at bottom of the stone, making the ridge invisible), they fooled local pawnshops into giving loans far exceeding the value of the triplets. It took some time before the truth was learned and publicized. But the manufacture of the jadeite triplets continued in the hope of fooling the world markets. Fortunately, discovery was made soon after they appeared in foreign markets, due principally to scientific methods developed and used by gemologists all over the world.

(Editors Note: The November-December, 1956 and the January-February, 1957 issues of THE LOUPE carried discussions on dyed jadeite in the New York Lab column, and also the identification procedures for it.)

(Continued from page 133)

cently imported very dark purple-red star rubies from India are almost invariably twinned in a rhombohedral direction, a condition which may give rise to three series of parallel lines around a "bullseye" center zone. Of course, the zoning may not be well developed in all three directions. In black star sapphires note the almost universal development of the basal repeated twinning planes, which may show up as bright "fractures" parallel to the girdle of the stone. These kinds of twinning in corundum are frequently mistaken for damage.

When repeated twinning in corundum is recognized, the alert jeweler will bear it in mind when setting, sizing or otherwise subjecting the stone to any forces. We once encountered a very large star sapphire that had been split neatly into three sections because it had not been removed from the setting. The ring had been slipped over a steel mandrill while the jeweler attempted to enlarge the shank by hammering! To be sure, the stone had possessed well-developed rhombohedral twinning.

One final observation comes to mind. Much of the actual damage in both diamonds and colored stones has been observed in stones with "knife-edge" girdles. Although the tendency in diamond cutting is toward too thick a girdle instead of too thin, because of the factor of weight recovery from the rough, a sufficient number of thin-girdled stones are encountered to make it imperative for the jeweler to consider rejecting these stones or using safe mountings. After all, the consumer frequently believes a diamond cannot break because it is the hardest thing in the world. Since not all consumers can be educated to the *truth,* it is well that he not learn the truth on his own stone!

Users of the Gemolite and American Gem Society members with their Diamondscopes are in a unique position to observe the procedures set forth in this paper.

Book Review

MY HOBBY IS COLLECTING ROCKS AND MINERALS, by David E. Jensen, Director of the Geological Division of Ward's Natural Science Establishment, Rochester, New York. 122 pages, well illustrated. Published by Childrens Press, Chicago, Illinois. New edition, 1958. Price $3.95.

The book holds much of interest for the boy or girl who has discovered the fascinating hobby of collecting rocks and minerals. The practical information contained in the book is presented in an easy-to-understand, nontechnical style, which will prove interesting to either the embryo collector or to the person who has already started the exciting hobby of collecting rocks and minerals. David E. Jensen is a geologist and mineralogist (A.B. Cornell University), and is director of the Geological Division of Ward's Natural Science Establishment. The main function of Ward's is to obtain mineral, rock and fossil specimens from all corners of the earth for redistribution to schools, colleges, museums, research organizations and private collectors.

The fifteen chapters of this large book (8½ x 10½ inches) give information on how to recognize minerals, how to classify rocks, where to find specimens, collecting equipment, how to display the minerals found, blowpipe experiments, how to catalog minerals, and includes various property tables. Also included are the names of museums having mineral exhibits, and publications with important information relative to various phases of the hobby (i.e., sources for equipment, specimen material and cutting material, and areas for collecting). An appendix lists minerals found in each state and Canada. Altogether, the book furnishes a comprehensive preview for the potential collector of rocks and minerals. It is also an informative guide for the person who is already engaged in the hobby.