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What Is a Synthetic?

Richard T. Liddicoat, Editor-in-Chief

In recent years, there has been an ongoing debate over what constitutes a synthetic and even whether the term itself is appropriate. In a letter to the editor in this issue, Dr. Eugene Love contends that the definition of *synthetic* as it has come to be used in gemology (i.e., to indicate the man-made equivalent of a natural gem) differs from the classic definition (i.e., that anything made by man is synthetic), and that the limited gemological definition should thus not be used. Moreover, manufacturers whose products virtually replicate the chemical composition and crystal structure of the equivalent mineral object strenuously to the term *synthetic* on the grounds that it has been used so often as a synonym for artificial (i.e., Dr. Love's classic use) that the public doesn't know the difference gemologically. Their objections also have merit.

Yet dealers of natural gemstones have protested the use of any other term to describe manufactured gem equivalents. Marketing skills today are such that it is easy, through the subtle use of language, to convince the consumer that a laboratory product with all the properties of the natural gem is the work of nature. The term *synthetic* leaves no doubt. In the view of the average stone dealer, the more rigid the restraints, the better. This viewpoint, too, deserves consideration.

Because these opposing positions both have merit, this whole subject is one that resists consensus in the jewelry industry. While the "limited" definition of synthetic has its drawbacks, the consumer is less likely to be misled in any costly fashion, in my view, than by other terms such as *created*, which may suggest that the design rather than the material was created by the manufacturer. "Man-made" (or "woman-made," in the case of Judith Osmer's Ramaura products) leaves little doubt, but does not clearly distinguish gem equivalents from nonequivalent simulants such as the diamond simulant cubic zirconia (which does not duplicate all of the properties, and attributes, of diamond as a synthetic diamond does). If a reasonable substitute for *synthetic*—one with a meaning that is unmistakable to consumer and dealer alike—were to be proposed, I would be delighted to endorse it. Until then, *synthetic* remains the best choice.

Another part of the *synthetic* controversy is represented in this issue by Dr. Karl Schmetzer's eloquently stated proposition that Inamori "synthetic" opal should not be regarded as synthetic (in the strict sense) because it does not contain water, whereas all natural opals do (although the Inamori product does contain the silica spheres that are essential to the play-of-color). One might propose the same argument for excluding flux synthetic emeralds, since all natural emeralds also contain water. Of course, water is considered sufficiently essential mineralogically that H_2O is part of the chemical formula for opal, while it is not for emerald. Here, however, we approach the issue of just how similar a synthetic must be to the natural gem material to merit the term *synthetic*, gemologically speaking.

There has been little objection over the years to the application of *synthetic* to flame-fusion synthetic spinel, which has a major compositional difference from any spinels found in nature. And yet, given that the water in natural opals can be extremely low in concentration, the Inamori product—even with no water whatsoever present—is closer in composition to many natural opals than most synthetic spinels are to their natural namesakes. To quote Dr. Kurt Nassau from a personal communication: "the feeling in the U.S.A. appears to be that the product does not need to be 'absolutely identical,' but essentially the same" to be called a synthetic. Obviously, there is need for some consensus as to how similar constitutes synthetic. At the one extreme is Dr. Schmetzer's narrow view, and at the other is Dr. Love's (to me) overly general definition. Clearly, we need definitions meaningful to consumers on which gemologists can agree.

AN UPDATE ON COLOR IN GEMS. PART 1: INTRODUCTION AND COLORS CAUSED BY DISPERSED METAL IONS

By Emmanuel Fritsch and George R. Rossman

Studies concerning the origin of color in gem materials have grown in sophistication in recent years, so that much new information is now available about natural color and its possible modification by various treatment processes. This three-part series of articles reviews our current understanding of gemstone coloration. The first part summarizes the factors that govern the perception of color, from the source of light to the human eye, and then examines in detail the role of one color-causing agent, dispersed metal ions, in the coloration of many gem materials, including ruby and emerald. The second part will explore charge-transfer phenomena and color centers as the cause of color in gems such as blue sapphire and Maxixe beryl. The series will conclude with colors that can be explained using band theory and physical optics, such as the play-of-color in opal and the blue sheen of moonstone feldspars.

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Acknowledgments: E.F. wishes to thank Professor Georges Calas, of the University of Paris VII, for his support in writing the original French version of this article. Special appreciation is due to Pat Gray for typing and correcting the "French accent" of the original manuscript. Thanks to Laurel Bartlett, John Hummel, and James Shigley for their constructive comments.

The origin of color in minerals in general and gem minerals in particular has been investigated with increasing sophistication in recent years. The new information provided by this research demonstrates that several mechanisms can contribute to the coloration of a single gem. Moreover, recent concerns about gemstone enhancement, which usually implies color enhancement, make it necessary to understand what happens during treatment and what changes in appearance can and cannot be achieved.

A strong interest in minerals arose early in history, because they are among the few natural materials that can permanently retain color, unlike flowers and plants, which fade or change with time. Colorful minerals such as iron oxides became the basic pigments of early paintings. Eventually, colored stones were cut and polished so they could be worn for adornment. From antiquity into the 18th century, color was also at the center of numerous superstitions, legends, and even "medical" treatments involving gems and minerals. Yellow stones, for example, were supposed to cure jaundice, and green stones were believed to soothe the eyes (Kunz, 1913).

As mineralogy became a science at the turn of the 19th century, color was used as a common indication in the identification of minerals. Soon, though, people discovered that crystals of the same mineral species could vary in color, and they began to surmise that some hues were related not to the mineral but to specific impurities (figure 1). Goethe, for example, was one of the first to relate the amethyst coloration in quartz to its iron content. The simple correlation between a certain color (e.g., "emerald green") and a given element (chromium) works to some extent, but modern research has shown that a number of very different processes can result in a similar color (Nassau, 1983).

Extensive collections of mineral and gemstone spectra

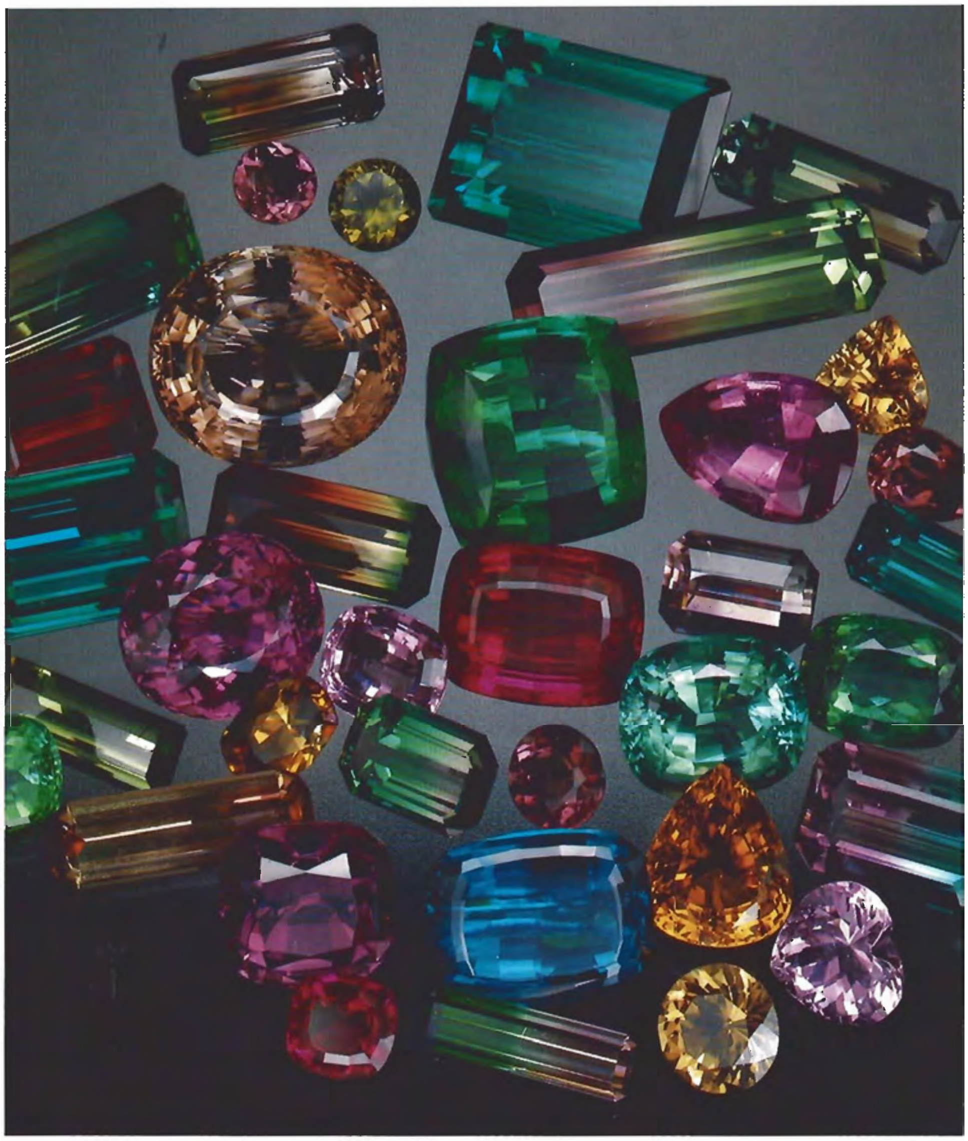


Figure 1. A number of different mechanisms are responsible for the variety of colors found in tourmaline. For example, the blue color of indicolite is caused by dispersed Fe^{2+}, but charge transfer between iron ions often contributes to the color of the green varieties. This article explains the influence of dispersed metal ions in the color of many different gem materials; the other two articles in this series will examine other causes of color such as charge transfer. Photo © Harold & Erica Van Pelt.

were assembled in the Soviet Union by a variety of researchers during the 1940s to 1960s. A theory developed in 1929 to explain color in crystalline solids was first applied to mineralogy in the late 1950s and was widely employed to explain color in minerals in the 1960s. In the U.S., the application of the science of color to minerals experienced its major impetus around 1970, with the publication of *Mineralogical Applications of Crystal Field Theory,* by Roger Burns. At approximately the same time, the optical properties of various synthetic colored crystals were described (e.g., Kittel, 1956; Farge and Fontana, 1979; Bill and Calas, 1978). Some long-standing and widely accepted explanations among gemologists were reevaluated according to new understanding of the origin of color. For example, organic products had long been held to be responsible for the blue coloration of fluorite, as mentioned in the 2nd edition of Webster (1970). In 1978, however, Bill and Calas demonstrated the role of ionizing radiation in generating color in fluorite. Nevertheless, many terms persist (such as "chrome" fluorite from Muzo, Colombia) that originate from erroneous beliefs about the origin of the color ("chrome" fluorite is actually colored by samarium).

In the course of modern research, five basic mechanisms have been identified as causes of color in gem materials: dispersed metal ions, charge-transfer phenomena, color centers, band theory, and physical optics. The purpose of this series of articles is to review the current knowledge of the origin of color in gems (see Fritsch, 1985, for a broader discussion of the cause of color in minerals in general), illustrating each mechanism with a number of examples and indicating briefly how treatment affects each type of coloration. First, however, it is important to understand the external factors that may influence our perception of the coloration of a gem. Therefore, this initial article examines the role of light and the human eye and then describes the best-known cause of color in gem materials: dispersed metal ions.

LIGHT AND THE HUMAN EYE

Three factors are important in establishing the color of a gemstone: the type of illumination, the stone itself, and the human eye. Depending on whether the light source is incandescent, fluorescent, or the sun, the appearance of a gem may vary considerably. Some gem materials demonstrate a total color change from one type of illumination to another (the "alexandrite effect," as explained, for example, in Farrell and Newnham, 1965). In addition, the stone itself will modify the incoming light in various ways, generally by absorbing part of it and transmitting the remainder. The transmitted light is then received by the human eye and transformed into a color perception by the brain. To understand the origin of color in the object itself, we must first briefly explore the roles of the light source and the human eye.

What Is Light? A prism will separate sunlight into the colors of the rainbow—a juxtaposition of violet, blue, green, yellow, orange, and red. Each of these colors, usually designated as "spectral colors," represents part of the visible spectrum (figure 2). Light of a particular wavelength carries a given energy—the shorter the wavelength, the higher the energy. The visible range extends, depending on the observer, from about 375 nm up to 740 nm. In sunlight, higher energy radiations (such as ultraviolet) and lower energy radiations (such as infrared) are also present.

One of the mechanisms that causes color is the absorption by a gemstone of part of the visible wavelengths that are passing through it. Thus, if a stone absorbs mostly red and violet-blue, as is the case with emerald, the light that is not absorbed (i.e., green, plus a little yellow and blue) passes through the stone, which will thus appear green.

As mentioned earlier, the color of some gem materials may be strongly modified when the source of illumination is changed. For example, alexandrite is green in sun (fluorescent) light and red in incandescent (e.g., candle) light. These two light sources contain different proportions of the spectral colors. The flame of the candle has an orange tint, because it is emitting much more yellow, orange, and red than blue. In fact, it is emitting so little blue light that a stone transmitting only blue, such as blue sapphire, will appear almost black when observed with such illumination. As an early French author stated, "it is the strangest thing in the world to see a magnificent sapphire parure become black in the candle's glimmer" (Pouget, 1752). Fluorescent light, however, emits a much larger proportion of light at the blue end of the visible spectrum and is, therefore, a more desirable source of illumination for blue stones.

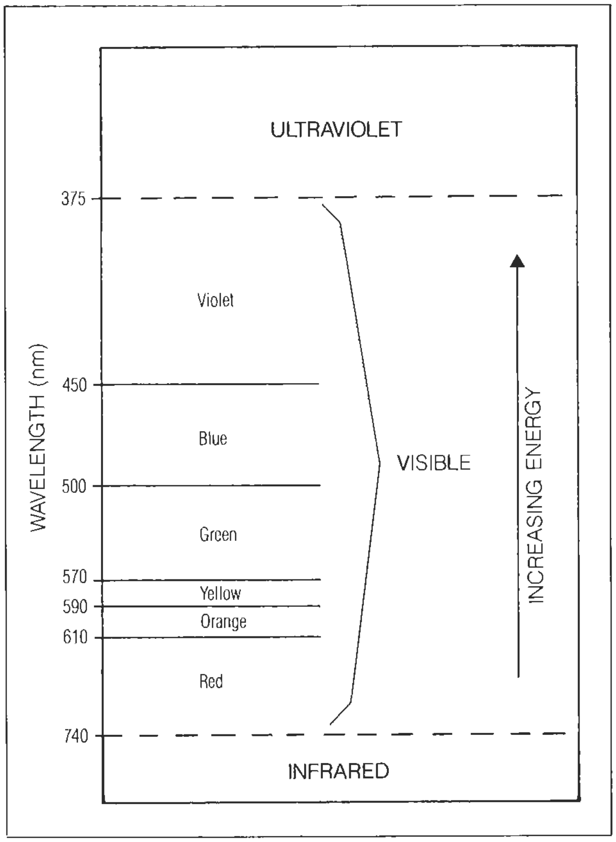


Figure 2. Each of the colors that make up visible light corresponds to a specific wavelength and energy range.

The Human Eye and Color. Two classes of light-sensitive cells are present in the retina of the human eye: cones and rods. If the light intensity is low (as in a dimly lit room), there will be no color sensation. Objects appear in shades of gray. This phenomenon is related to the use of the rods, which are responsible for vision under poor lighting and contain only one pigment (see, e.g., Wasserman, 1978).

At higher levels of illumination, color perception involves the cones. Each cone contains one of

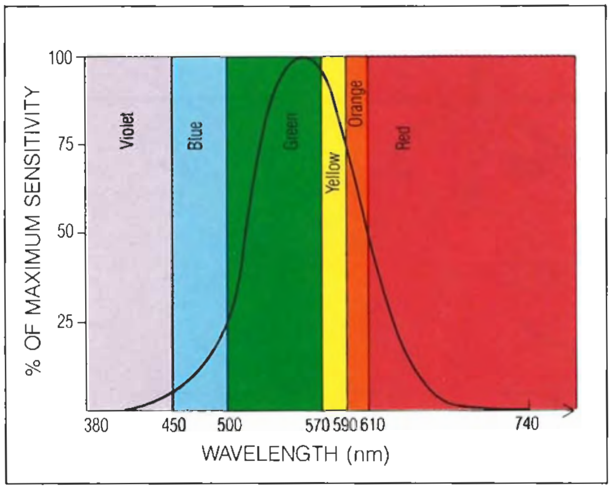


Figure 3. As evident from this graph of the spectral sensitivity of the human eye, a person's greatest sensitivity is to the color green. Adapted from Duplessis (1985).

three fundamental pigments, which have a maximum absorption in the red, the blue, and the green, respectively. The color we perceive is a combination of the responses coming from the three different types of cones, which depend in turn on their levels of reaction to a given light stimulus. The human eye is not equally sensitive to each visible color. Rather, it is most sensitive to green, as shown in figure 3 (Duplessis et al., 1985). It is interesting to note that the peak of this curve coincides with the peak wavelength of the solar radiation at the surface of the earth. In fact, the uneven spectral sensitivity of the human eye has long been viewed as an adaptation to life with sunlight (Nassau, 1983).

THE INTERACTION OF LIGHT WITH GEMSTONES

Many things can happen to the light entering a cut stone: It can be reflected, refracted, diffracted, scattered, absorbed, or simply transmitted. Although absorption is by far the most important factor in determining color, one must realize that several combinations of these different processes are possible; for example, a colorless (nonabsorbing) gem may acquire color by diffraction (e.g., opal). We will, therefore, describe the numerous causes of absorption in the first two parts of this series, and then, in the last part, will consider the remaining possibilities that influence color. In so doing, we will follow as well an increase in the size of the color-causing agent. Dispersed ions are single atoms, and thus the smallest possible cause of color. Charge-transfer phenomena and the creation of color centers both require small groups of atoms. A much larger cluster of atoms is involved in band theory. Lastly, physical structures of considerable dimension compared to the size of the atom (lamellae, for example) are responsible for colors explained by physical optics. In the case of these large structures, the color is determined primarily by their size and shape; for a few gem materials, texture has a greater impact on color (and phenomena) than does chemical composition.

We will begin this discussion of the causes of color in gemstones by examining how color is induced in gem materials through the absorption of light by dispersed metal ions. "Dispersed" here means that the ions are sufficiently isolated from one another by other types of atoms that they never interact.

COLORS CAUSED BY DISPERSED METAL IONS

How Does an Ion Absorb Light? An atom consists of a positively charged nucleus and negatively charged electrons, which are in motion about the nucleus. The identity of the atom is determined by the composition of the nucleus. When the number of positive charges in the nucleus is equal to the number of negative charges (electrons) around it, the atom is neutral. When it is not electrically neutral (e.g., when it has an extra electron), it is called an ion. The actual electric charge of the ion is referred to as the valence state, and is symbolized by a sign and a number attached to the symbol of the atom, such as Cr^{3+} for chromium with three electrons missing, or O^{2-} for oxygen with two additional electrons. Sometimes a corresponding adjective exists: Ferrous iron is Fe^{2+} and ferric iron is Fe^{3+}.

Electrons are conveniently represented as moving around the nucleus within specific volumes called orbitals (figure 4). A given number of electrons revolving in a set of orbitals represent a certain energy for this particular ion. Absorption occurs when illumination causes one electron to move from one orbital to another orbital of higher energy. The corresponding change in energy of the ion equals the energy of the light absorbed. This can be illustrated schematically in energy-level diagrams, such as in figure 5.

When an electron absorbs light it changes its

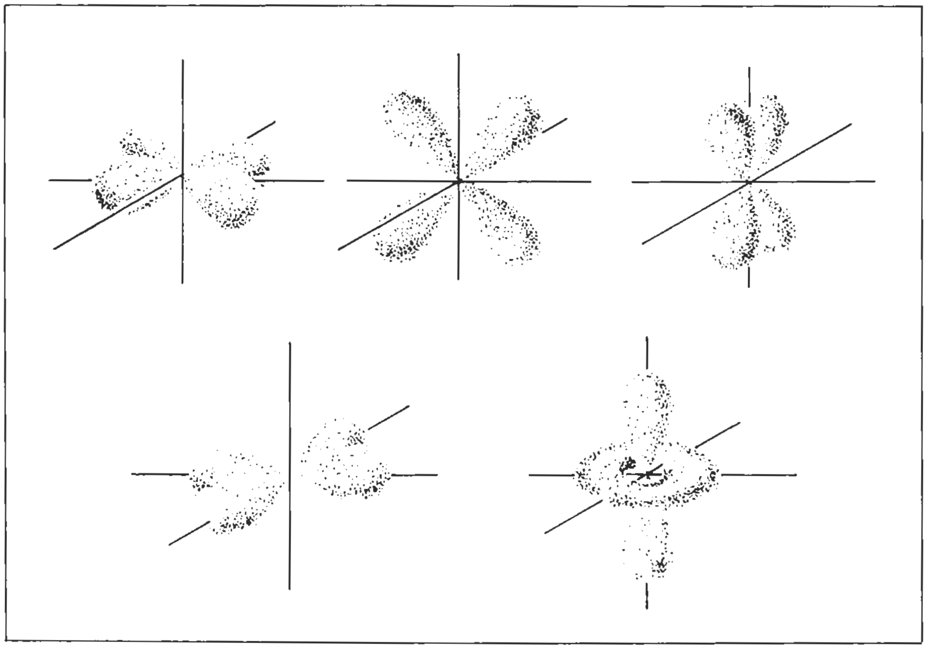


Figure 4. These are some orbitals of metal ions that cause color in gem materials. The electrons move around the nucleus within these volumes of specific shape and direction. Adapted from Fyfe (1964); reproduced with permission.

orbital. This process is called a transition, from the ground state (low-energy initial configuration of the electrons) to the excited state (a higher-energy configuration). Figure 5 shows how an absorption band as seen with a hand-held spectroscope relates both to a (more accurate) spectrum recorded on a spectrophotometer and to an energy diagram that indicates the various energy levels involved. When the transmitted light is observed with a hand-held spectroscope, the absorption will give rise to a dark band (the missing wavelengths). With a spectrophotometer, it appears as a broad absorption band on the graph (again, see figure 5).

The excited state is intrinsically unstable, so the electron must return to its normal ground state. Generally, there are two ways for this to happen. The more common way is for the electron to release the energy to the crystal lattice in the form of atomic vibrations (heat). The other way, which can be of great gemological significance, is

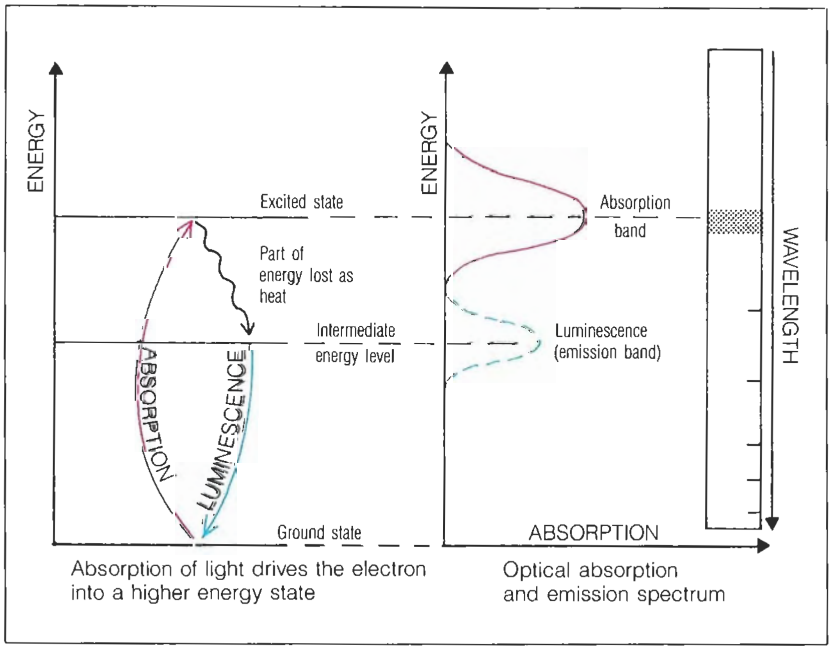


Figure 5. An absorption spectrum as seen in a hand-held spectroscope is compared with that obtained with a research spectrophotometer and the relevant representation of the fundamental mechanics of light absorption. When a crystal absorbs light, electrons are moved from the low energy (ground) state to a higher energy (excited) state. This energy is ultimately lost when the electron returns to its ground state by dissipating the energy either as heat in the crystal or through the emission of light (luminescence).

luminescence, in which part of the energy acquired in the transition is converted into light emitted by the stone. Since the electron cannot emit more energy than it absorbed, luminescence must occur with an emission of energy equal to or less than that acquired in the absorption, as can be seen in figure 5. This means that the wavelength of luminescence must be equal to or longer than that of absorption. For example, Cr^{3+} in ruby absorbs in the yellow-green and luminesces in the red. This is also why so many gemstones emit visible (low energy) luminescence when exposed to ultraviolet (high energy) radiation. Absorption in the ultraviolet spectral range results in an emission at a lower energy, that is, in the visible range.

The Identity of the Ion Affects the Color. In actuality, very few ions have the ability to absorb visible light. The ones most commonly encountered in gemstones are the ions of the following elements: titanium (Ti), vanadium (V), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), and copper (Cu). Although a number of other elements can also cause color, such as cerium in some orange cubic zirconia and uranium in heat-treated blue zircon, they tend to be restricted to only one material.

In most cases, different metal ions produce different colors. For example, in general, colors produced by iron will be quite different from those generated by chromium in the same mineral; that is, in spinel, Fe^{2+} causes a grayish blue color, while Cr^{3+} causes red. The following examples illustrate the various factors that influence how metal ions give rise to color in gem materials.

The Influence of the Valence State. The valence state of an ion exerts a strong influence on both the hue and the intensity of the color. While a number of valence states are possible for each element, only a few are important in gemology (a reflection of the limited range of chemical conditions that lead to the formation of gem materials). For example, manganese is known in valence states from Mn^0 through Mn^{7+}, but it occurs commonly in gems as Mn^{2+} and Mn^{3+}. Beryl containing Mn^{2+} exhibits a delicate pink hue (morganite), while Mn^{3+}-containing beryl occurs as bright red (red beryl), as seen in figure 6. A different charge of the same element generally produces a different hue. In the case of manganese, absorption of light in a material occurs with much greater efficiency if this material contains Mn^{3+} rather than Mn^{2+}. The reason for such differences has to do with the probability of occurrence of certain transitions, and is explained by certain rules of quantum mechanics, which are beyond the scope of this article. Because Mn^{2+} (and Fe^{3+}) transitions have a low probability of occurrence, they give rise to low-intensity absorptions in the visible range (Burns, 1970) and, consequently, to pale colors. Transitions for Mn^{3+} and most of the other metal ions occur with much greater probability, producing stronger absorptions and brighter colors.

Figure 6. The difference in color intensity between a pink beryl (morganite) from Brazil, colored by Mn^{2+}, and a red beryl from Utah, colored by Mn^{3+}, illustrates the importance of the valence state of the coloring ion. Photo by Shane McClure.

Various treatment methods can have a powerful influence on the color of gem materials by modifying the valence state of the metal ions they contain. For example, Fe^{3+} can be changed into Fe^{2+} by heating in reducing conditions (thus turning green beryl to blue aquamarine; see figure 7 and Nassau, 1984). Irradiation (X-rays, gamma rays, etc.), which can easily remove electrons from atoms, very often produces the opposite effect of heat treatment; for example, it converts Fe^{2+} into Fe^{3+}, thus turning aquamarine into golden yellow beryl (Goldman et al., 1978). In the production of synthetic amethyst, irradiation is used to transform Fe^{3+} into the Fe^{4+} necessary to obtain the purple color (Balitsky and Balitskaya, 1986). In fact, the only way treatment can affect color caused by dispersed metal ions is by modifying the valence state.

Figure 7. In beryl, Fe^{3+} causes yellow and Fe^{2+} causes blue; green beryl is a mixture of Fe^{3+} and Fe^{2+}. The common practice of heating green beryl modifies the valence state of the Fe^{3+} such that the yellow color is removed and only blue (aquamarine) remains. Photo © Harold & Erica Van Pelt.

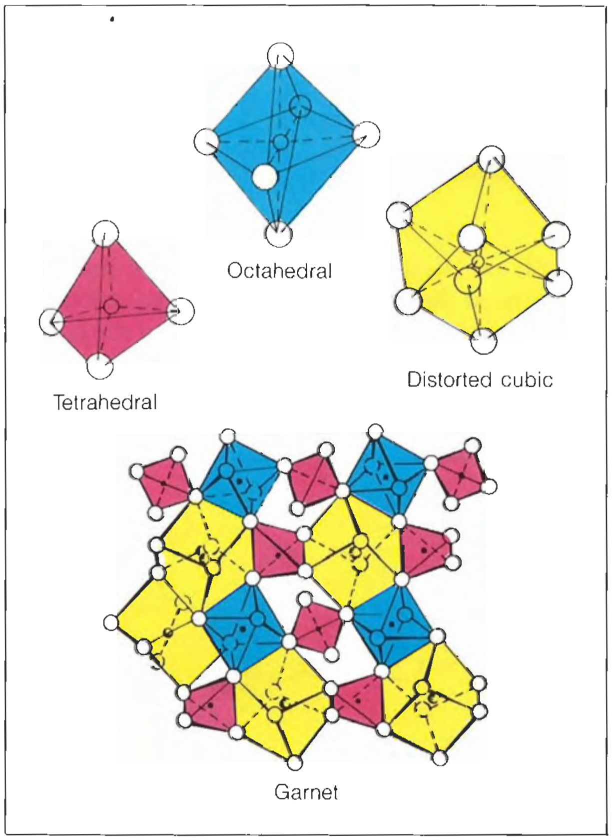
The Nature of the Neighboring Atoms Influences Color. While the identity of the ion itself is important, the nature of its neighboring atoms is of equal significance. In most gem materials, the color-producing ion is surrounded by and connected to oxygen ions. Different neighboring atoms, however, will lead to different colors. For example, both green sphalerite and blue spinel are colored by Co^{2+} in tetrahedral sites, but the Co^{2+} ion in green sphalerite (like the metal ions in all sulphides) is connected to sulphur, while that of blue spinel is connected to oxygen (Romeijn, 1953; Marfunin, 1979; Shigley and Stockton, 1984).

Ion Coordination. The coordination of an ion refers to the number of atoms to which it is directly bonded and the geometry of this arrangement. Color-producing ions usually are surrounded by different numbers and arrangements of oxygen ions. Only three types of coordination are commonly encountered in gems (in order of frequency): octahedral, tetrahedral, and distorted cubic (see figure 8). In an octahedron, the central metal ion has six neighbors to which it is bonded; if no distortion occurs, they are all the same distance from the atom. The tetrahedron provides four surrounding ions; again, they are equidistant from

Figure 9. These two stones show the difference in color caused by a difference in coordination: Co^{2+} is in tetrahedral coordination in this blue spinel, and in octahedral coordination in the pink cobaltocalcite. Photo by Shane McClure.

Figure 10. Both green peridot and red pyrope-almandine garnet are primarily colored by Fe^{2+}. The striking difference in color is caused by the difference in ion coordination, which is octahedral in peridot and distorted cubic in garnet. Photo by Shane McClure.

Figure 8. Three types of ion coordination are commonly found in gem materials: tetrahedral (four neighbors), octahedral (six neighbors), and distorted cubic (eight neighbors). As illustrated here, the garnet structure exhibits all three of these common coordinations (the tetrahedrons are in red, the octahedrons in blue, and the distorted cubic sites in yellow). Adapted from Novak and Gibbs (1971).



the central metal ion if there is no distortion. In distorted cubic coordination, the central metal ion has eight neighbors; this coordination is gemologically significant only for garnet and zircon.

Drastic differences in color may arise when the same metal ion occurs in different coordinations, as illustrated by the examples of Co^{2+} (figure 9) and Fe^{2+} (figure 10). Cobaltocalcite is popular as a collector's item because of its vivid pink color, which is due (as the name suggests) to cobalt; in calcite it is in octahedral coordination as Co^{2+}. "Cobalt blue" spinel derives its vivid color from Co^{2+} as well. In this case, however, the cobalt is tetrahedrally coordinated, resulting in a striking blue color.

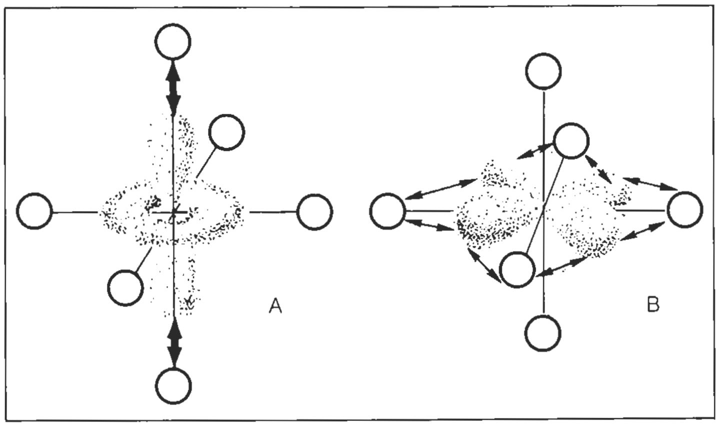
A similar dramatic modification in hue is encountered with Fe^{2+}. The green color of peridot results from the presence of ferrous iron in two slightly distorted octahedral sites, but Fe^{2+} imparts a deep red color to almandine garnet (Loeffler and Burns, 1976). The basic reason for this difference is the coordination of the Fe^{2+} ion, which in garnet is a distorted cube (again, see figure 8).

To understand why changes in the geometry of the environment of the ion have such a profound effect on color, we must reconsider the orbitals of the central ion. These orbitals project outward toward the oxygen ions in the coordination environment: Some of the orbitals point directly at these surrounding ions, some fall in between (see figure 11). Electrons in these orbitals of the central ion are electrostatically repelled by the electrons in the neighboring oxygen ions. The intensity of repulsion from the negatively charged oxygen ions

Figure 12. The strong brown-green pleochroism of this 12-cm-long epidote crystal from Pakistan is thought to be due to a geometric distortion of the octahedral iron site. Specimen courtesy of the Sorbonne Collection, Paris; photo © Nelly Bariand.

depends on the number of oxygen atoms, their distance from the central metal ion, and the particular orbital the electron is in. When an electron in the central ion absorbs light and moves from one orbital to another, the energy required depends on the particular electrostatic repulsion experienced during this move. Consequently, the amount of repulsion will be different in the case of octahedral and tetrahedral environments and, thus, they will produce different colors.

Figure 11. Electrostatic repulsions of different intensities are experienced by electrons in different orbitals of the metal ion, as illustrated here in the case of octahedral coordination. (A) When an orbital of the metal ion points directly toward neighboring oxygen ions, the electrostatic repulsion between the electrons in the orbital and the oxygen ions, both charged negatively, is intense. (B) When an orbital points between oxygen ions, the repulsion is smaller. This difference is ultimately responsible for the different colors that arise from a given ion in different coordination geometry (see figures 9 and 10).



Pleochroism. The color of a gem mineral also depends on its orientation with respect to the light source, sometimes radically. For example, epidote shows brown in one direction and green in another (figure 12). The cause in epidote is that certain electron transitions are favored along certain crystallographic axes. This effect is most prominent in minerals where the octahedral sites are significantly distorted from the ideal geometry. In this case, when an electron moves from one orbital to another, a different amount of energy is required in different orientations. (It must be noted, however, that this is only one origin of pleochroism in gem materials. Strong pleochroism can also be seen in coloration that involves charge-transfer processes or color centers, as will be described in part 2 of this series.)

Influence of the Details of the Coordination Environment. A particular ion, in a single valence state, can produce a variety of colors in different gem materials even though it is surrounded by the same number of oxygen ions. For example, ruby, emerald, and alexandrite all owe their vivid coloration to Cr^{3+} in octahedral coordination (Loeffler and Burns, 1976). Why, then, do ruby and emerald differ in color, and why does alexandrite show different colors under different light sources? Figure 13 shows the optical absorption spectra of these three minerals. The spectra of both ruby and emerald consist of two large absorption bands in the visible region. The major difference is the exact position of the peaks of the two absorption bands. They are situated at highest energy (shortest wavelength) for ruby, which has two transmission windows—one centered in the blue (480 nm) between the major absorption bands and one centered in the red (wavelengths longer than 610 nm). Because the eye is more sensitive in the red just above 610 nm than it is in the blue (see figure 3), the ruby appears red (figure 14). On the other hand, the transmission window for emeralds is centered in the green, where the eye is most sensitive, giving the stones their rich characteristic color (figure 15).

The difference between ruby and emerald can be explained by the particulars of the crystallographic environment around chromium. Factors such as the distance between chromium and its neighboring oxygen atoms, and the details of the local geometry, contribute to the local electrostatic field about the chromium. These details are sufficiently different for the two minerals that the absorption features, though similar in shape for both minerals, will appear at lower energies in beryl than in corundum (again, see figure 13).

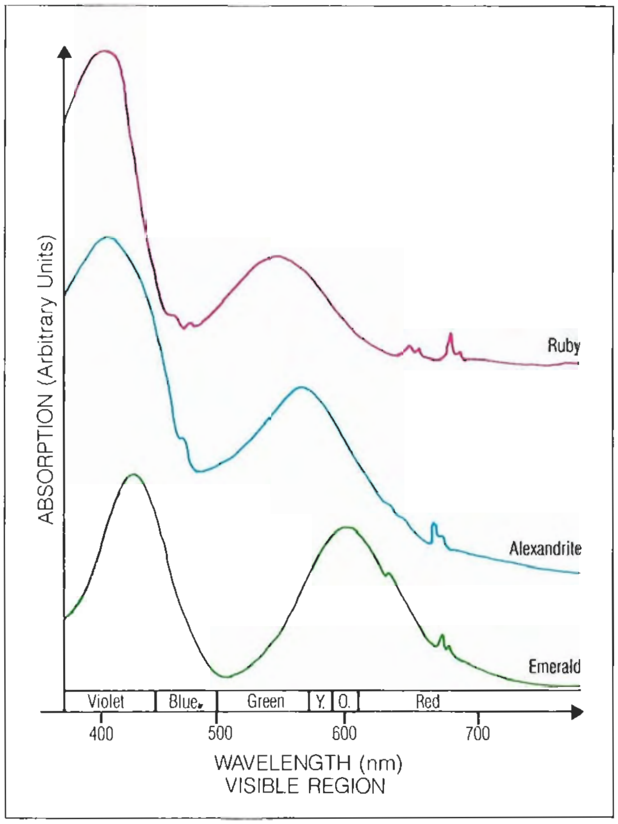


Figure 13. Optical absorption spectra of a ruby from Burma, an alexandrite from Tanzania, and an emerald from Colombia. As the chromium absorption bands shift toward longer wavelengths, the color changes, respectively, from red, to red and green (under different types of light), to green only.

In alexandrite, which is one of the chromium-bearing varieties of chrysoberyl, the Cr^{3+} site is intermediate between those of ruby and emerald. Consequently, alexandrite transmits both bluish green and red (again, see figure 13). In sunlight, it will appear mostly green, because this is where solar light has its maximum intensity and the human eye has its greatest sensitivity. When viewed with incandescent light, however, the stone appears red because incandescent light contains a relatively larger proportion of red than does solar light (an excellent illustration of this color change appears in Koivula, 1987).

As another example, red corundum and green zoisite are both colored by Cr^{3+} in octahedral coordination, substituting for Al^{3+} in the crystal structure. The difference in color is due to a

Figure 14. Because of the position of the Cr^{3+} absorption bands in its visible spectrum, ruby has a red body color. In addition, rubies not only transmit red, but they also emit it, so that their color can be reinforced by the strong red luminescence, especially in Burmese stones. The deep red body color and natural red luminescence of these two 20-ct rubies (set in earrings) is enhanced by the cabochon cut. Courtesy of Collection Chaumet, Paris; photo © Nelly Bariand.

difference in the distance between the metal ion (chromium) and the neighboring oxygen atoms. In zoisite structure, Cr^{3+} occupies a site where the average metal-oxygen distance is 1.967 Å (Dollase, 1968). In corundum structure, however, it is much shorter—1.913 Å (Newnham and De Haan, 1962). Therefore, the Cr^{3+} ion experiences more electrostatic repulsion in corundum, and its absorption features are shifted to higher energies than in zoisite, causing a contrast in color.

One factor that might influence the environment of a given ion, in particular the metal-oxygen distance, is its concentration. Various authors have observed this "concentration effect" in corundum, spinel, and garnet (e.g., Calas, 1978). In the red Mg-Al garnet pyrope, Cr^{3+} ions are present at low concentration, and the Cr-O distance is 1.96 Å (Calas, 1978). In the deep purple Mg-Cr garnet knorringite, however, Cr^{3+} ions occur in the same coordination, but at higher concentration, with a Cr-O distance of 2.03 Å (Berry and Vaughan, 1985). Thus, in a single mineral group, such as garnet, an increase in concentration of Cr^{3+} will lead to an increase in the Cr-O distance and modification of the color from red to purple.

Remarks. The various phenomena that we have described can be approached quantitatively by the use of chemical theories such as crystal field theory (Burns, 1970). These theories can explain the color in gems equally well in the case of either a major constituent (such as iron in peridot and garnet) or a minor component (such as chromium in ruby and emerald). The same type of reasoning can be applied to dispersed metal ions in noncrystalline materials such as glasses; for example, the peridot-like green color of tektites and moldavites is also due to Fe^{2+}. Oversimplifying a little, metal ions create basically the same spectra in glass simulants as in the gems themselves.

Table 1 lists the variety of colors caused by different metal ions in gem materials. When reviewing this list, please keep in mind that many gems are colored by a combination of causes (some of which will be discussed later in this series of articles). For example, the different shades of red in ruby are due to the influence of minor absorptions caused by small amounts of dispersed iron and vanadium ions (Harder, 1969). Also, the same color (e.g., green) can occur in a given gem material (e.g., nephrite) for different reasons (dispersed octahedral Cr^{3+} produces "emerald-green," while dispersed octahedral Fe^{2+} gives a more yellowish green).

CONCLUSION

The first article of this series on the origin of color in gem materials has reviewed the best-known cause of color: absorption of light by dispersed metal ions. We have demonstrated that not only is the identity of the metal ion important, but its valence state, the nature of the neighboring atoms, its coordination, and the details of its environment may also have a dramatic effect on the color of a gem material. The only way treatment can affect a

Figure 15. The vivid green of these Colombian emeralds results from the distinctive coordination environment of the color-causing Cr^{3+} ions. The emerald in the pendant weighs 37 ct; the two drops in the earrings weigh a total of 49 ct. Jewelry courtesy of Harry Winston, Inc.; photo © Harold & Erica Van Pelt.

TABLE 1. Dispersed metal ions and the colors they cause in various gem materials.

Ion and coordination	Color and gem material
Ti^{3+} octahedral	No known gems where the origin of color has been positively proved to be dispersed Ti^{3+}, although the case of rose quartz is under discussion (see Cohen and Makar, 1985)
V^{4+} octahedral	**Blue:** zoisite/heat treated = tanzanite (Hurlbut, 1969) **Green:** apophyllite (Rossman, 1974)
V^{3+} octahedral	**Blue:** axinite (Schmetzer, 1982) **Brown-violet:** zoisite/untreated (Hurlbut, 1969) **Green:** beryl/vanadium emerald (Wood and Nassau, 1968); grossular/tsavorite (Gübelin and Weibel, 1975); some kyanites, diopsides, uvites, spodumenes and kornerupines (Schmetzer, 1982) **Color-change effect:** corundum and some rare pyropes and pyrope-spessartines (Schmetzer et al., 1980)
Cr^{3+} octahedral	**Blue:** kornerupine (Schmetzer, 1982) **Green:** beryl/emerald, spinel (Vogel, 1934); spodumene/hiddenite, diopside/chrome diopside, jadeite/chrome jadeite, nephrite, euclase, andradite/demantoid, some rare olivines, variscite (Anderson, 1954–55); titanite/chrome sphene, zoisite (Schmetzer, 1982); uvarovite (Calas, 1978) **Color-change effect:** chrysoberyl/alexandrite (Farrell and Newnham, 1965); some pyropes (Schmetzer et al., 1980) **Red to violet:** corundum/ruby, spinel (Vogel, 1934); some pyrope (Manning, 1967a); taaffeite (Schmetzer, 1983); topaz (Anderson, 1954–55); stichtite
Mn^{3+} octahedral	**Red to violet to pink:** beryl/red beryl (Shigley and Foord, 1984); piemontite (Burns, 1970); some elbaites/rubellites, sugilite (Shigley et al., 1987); rhodonite (Gibbons et al., 1974); zoisite/thulite **Green:** andalusite/viridine (Smith et al., 1982)
Mn^{2+} octahedral	**Pink:** beryl/morganite (Woods and Nassau, 1968); rhodocrosite (Lehmann, 1978); lepidolite (Faye, 1968); titanite (Mottana and Griffin, 1979) **Greenish yellow:** some rare elbaites (Rossman and Mattson, 1986)
Mn^{2+} dist. cubic	**Orange:** spessartine (Manning, 1967a)
Fe^{3+} octahedral	**Yellow:** chrysoberyl (Loeffler and Burns, 1976) **Yellow green:** jadeite (Rossman, 1981); epidote (Burns, 1970); andradite (Manning, 1967b)
Fe^{3+} tetrahedral	**Yellow:** orthoclase and other feldspars (Hofmeister and Rossman, 1983); sillimanite (Rossman et al., 1982)
Fe^{2+} octahedral	**Blue:** elbaite/indicolite (Dietrich, 1985) **Yellowish green to green:** olivine/peridot (Loeffler and Burns, 1976); diopside, actinolite/nephrite (Burns, 1970); natural glasses/moldavite, tektite (Pye et al., 1983)
Fe^{2+} tetrahedral	**Blue:** gahnite and "gahnospinel" (Dickson and Smith, 1976)
Fe^{2+} dist. cubic	**Red:** pyrope, pyrope-almandine (rhodolite), almandine (Manning, 1967a)
Co^{2+} octahedral	**Pink:** calcite/cobaltocalcite (Webster, 1970) **Green:** sphalerite (Marfunin, 1979)
Co^{2+} tetrahedral	**Blue:** spinel (Shigley and Stockton, 1984); staurolite (Cech et al., 1981)
Ni^{2+} octahedral	**Green:** clay inclusions in chrysoprase and some opals, e.g., prase opal (Koivula and Fryer, 1984)
Cu^{2+} octahedral	**Blue:** turquoise and chrysocolla (Lehmann, 1978); azurite (Marfunin, 1979) **Green:** malachite and dioptase (Lehmann, 1978)

color caused by dispersed metal ions is by modifying the valence state. In recent years, we have become aware of the importance of other types of coloration, such as charge transfer and color centers. Heat treatment can induce or increase charge transfers, and irradiation often creates color centers. These two causes of color will be examined and illustrated with a number of examples in the next article in this series. The least common origins of color in gem materials, band theory and physical optics, will be discussed in the third and last part.

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THE LENNIX SYNTHETIC EMERALD

By Giorgio Graziani, Edward Gübelin, and Maurizio Martini

The Lennix synthetic emerald, currently manufactured in France, is a dark green, moderately transparent to translucent material grown by flux fusion. With the microscope, zones of lighter and darker green are evident. For the most part, the gemological properties of this synthetic emerald overlap those of natural emeralds, although the low refractive-index and specific-gravity values are good indicators that this material is synthetic. The presence of "wispy veil" inclusions provides conclusive proof of synthetic origin, as do the chemical analyses, infrared transmission spectra, and cathodoluminescence.

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As the techniques of crystal growth have become increasingly sophisticated, greater numbers and types of synthetic emeralds have entered the marketplace. One of these products, the Lennix synthetic emerald, is currently being manufactured by the Société France pour la Distribution de Produits Manufacturés, in Cannes, France (figure 1). In 1966, Mr. L. Lens, now president of the manufacturing company, first accomplished the synthesis of microscopic emerald clusters. Years of research and refinement followed, and in the period 1982–1983, Mr. Lens finally obtained gem-quality synthetic emeralds in sizes suitable for use in jewelry. Mr. Lens reports that the production capacity of the firm is currently 50,000 ct of rough crystals per year, an amount that could be doubled with the addition of a second furnace. The material is now available in France (and has already been mistaken for "African emerald" by some jewelers). Since the distribution of the material is controlled by a Canadian company, it is likely that this material will soon be introduced in Canada and the United States (E. Fritsch, pers. comm., 1987).

Although Farn (1980) examined a number of the early Lennix synthetic emeralds and pointed out some distinctive characteristics of these stones, the present authors felt that a detailed examination of the material and its inclusions was warranted to describe the means by which it could be separated from natural emeralds and other synthetics. To aid in this project, Mr. Lens supplied eight rough crystals and one faceted stone. The samples were first tested for the standard gemological properties, and then chemical analyses, cathodoluminescence, X-ray topography, X-ray diffraction, and advanced inclusion analyses were performed. The results of these tests are provided here.

METHOD OF SYNTHESIS

Mr. Lens reports that the Lennix synthetic emeralds are

Figure 1. A 1.32-ct faceted Lennix synthetic emerald and a 1.42-ct crystal section of the material. Photo © Tino Hammid.

grown by the flux-fusion process. Crystallization takes place at atmospheric pressure, and follows a rather involved cycle of temperatures, in the region of 1000° ± 100°C, established to compensate for variations in the composition of the flux during the growth process.

TEST SAMPLES AND VISUAL APPEARANCE

The synthetic samples examined by the authors are in the form of eight tabular hexagonal crystals and one cut specimen. The rough crystals are characterized by a predominant basal pinacoid. They range in size from 13.9 × 9.6 × 3.0 mm to 9.2 × 6.9 × 3.2 mm; the cut sample weighs 1.30 ct and measures 7.90 × 6.12 × 3.12 mm. To the unaided eye, the Lennix synthetic emeralds appear dark green and homogeneous in color (again, see figure 1). Microscopic observations, however, reveal the presence of more intense peripheral color zones parallel to the c-axis.

The samples range in clarity from moderately to heavily included. Consequently, they vary from stones of medium transparency to those with areas that are translucent to almost opaque.

STANDARD GEMOLOGICAL TESTING

The samples were subjected to standard gemological tests. The results are shown in table 1 and discussed below.

Refractive Indices. When tested with a gemological refractometer, the faceted Lennix synthetic emerald was determined to be uniaxial negative. Refractive indices were determined on microsamples isolated by means of the MEA apparatus (Graziani, 1983), from within both the light and dark green areas.

The values* are: ϵ = 1.556–1.562 (1.559) and ω = 1.558–1.566 (1.562), with a corresponding birefringence for the mean values of 0.003, for the light green areas; and ϵ = 1.555–1.565 (1.560), ω = 1.560–1.568 (1.564), with a mean birefringence of 0.004, for the dark green areas. The faceted stone shown in figure 1, for example, revealed refractive indices of ϵ = 1.559, ω = 1.562, with a birefringence of 0.003.

The low values of the light green areas (and the stone in figure 1) are characteristic of flux-grown synthetic emeralds and provide some indication of synthetic origin. However, an identification should not be based on these values alone.

Dichroism. Using a dichroscope, we observed pronounced pleochroic colors of bluish green for the ordinary ray and yellowish green for the extraordinary ray, both also commonly observed in natural emeralds.

**The extreme values of the constants are given, with mean values in parentheses.*

TABLE 1. The gemological properties of the Lennix flux-grown synthetic emerald.

Properties that overlap those of natural emeralds	
Pleochroism	Strong bluish green parallel to the c-axis; yellowish green perpendicular to the c-axis.
Absorption spectrum[a]	Optic-axis direction absorption lines at 477, 637, 646, 662, 680, and 683 nm; a vague general absorption from 400 to 480 nm and a broad band of absorption between 590 and 610 nm. Perpendicular to optic-axis direction: same as above, with the exception that the 477-nm line is absent.
Color-filter reaction	Strong red
Fluorescence	
Long-wave U.V.	Bright red
Short-wave U.V.	Weak orange-red
Key identifying properties	
Refractive indices[b]	Light green: $\epsilon = 1.556–1.562$ (1.559) $\omega = 1.558–1.566$ (1.562) Dark green: $\epsilon = 1.555–1.565$ (1.560) $\omega = 1.560–1.568$ (1.564)
Birefringence[b]	Light green $= 0.003$ Dark green $= 0.004$
Specific gravity[c]	Around 2.65–2.66
Inclusions	Opaque, tube-like inclusions aligned parallel to the c-axis; sequential growth layers, with primary flux inclusions and foreign crystallites; slender prismatic crystals of synthetic phenakite and synthetic beryl; "wispy veils," two-phase inclusions.

[a] *As observed through a hand-held type of spectroscope.*
[b] *The extreme values of the constants are given, with mean values in parentheses. Birefringences are given for the mean values.*
[c] *Estimated with heavy liquids.*

Color-Filter Reaction. Observed through the Chelsea filter, the crystals appear a vivid red, again as can be seen in many natural emeralds.

Specific Gravity. The specific-gravity values for flux-grown synthetic emeralds of various manufacturers are frequently lower than the values for natural emeralds; flux-grown synthetic emeralds usually float when tested in a standard 2.67 (specific gravity) heavy liquid. A few of the Lennix synthetic emeralds were tested in 2.67 liquid; on the basis of the rate of ascent, the specific gravity was estimated to be approximately 2.65–2.66.

Absorption Spectra. The visible-light absorption spectrum of the faceted Lennix synthetic emerald shown in figure 1 was examined with a Beck hand-held type of spectroscope. The observed spectrum appeared to be the same as that previously described for both synthetic and natural emerald (Liddicoat, 1981). This optical absorption spectrum was confirmed, using a Cary 219 dual-beam spectrophotometer, over the spectral range from 400 to 800 nm. The following were identified: a doublet at 683 and 680 nm; bands at 662, 646, and 637 nm; and a wide band between 610 and 590 nm. An additional line at 477 nm can be seen only when looking at the spectrum down the optic axis direction (i.e., parallel to the c-axis); it is not visible when the spectrum is examined perpendicular to the optic axis. This phenomenon was observed with both the "hand-held" spectroscope and the spectrophotometer.

Fluorescence. When exposed to long-wave ultraviolet radiation, the specimens glowed bright red, and with short-wave U.V. radiation they revealed both transparency and a dim orange-red fluorescence. While this fluorescence might be an indicator that the stone is synthetic, it should be noted that some high-chromium Colombian emeralds will fluoresce bright red to long-wave U.V. radiation. Exposure to X-rays caused a distinct, yet dull, red fluorescence.

CHEMISTRY AND ADDITIONAL TESTING

Chemical Analyses. Each specimen was analyzed by means of a JEOL JXA-50A electron microprobe on both the pale green and the deep green zones. The chemical data reported in table 2 refer to average values obtained from no less than five spots for each sample.

The data show fairly high contents of FeO and MgO for a synthetic emerald and low amounts of alkalies as compared to most natural emeralds. However, the FeO and MgO contents are lower than the average in most natural emeralds and, along with the low content of alkalies, may be responsible for the low refractive-index, birefringence, and specific-gravity values (Folinsbee, 1941; Sherstyuk, 1958; Winchell and Winchell, 1951). The chromium content in the deep green areas is high, but is comparable with data reported for natural and other synthetic emeralds.

Cathodoluminescence. Cathodoluminescence determinations were carried out on all samples using a luminoscope manufactured by Nuclide Corp.

USA. Electrons were produced using pure helium as a carrier gas. The data obtained were quite similar for all samples. Red luminescence similar to or weaker than that of Chatham or Linde hydrothermal synthetic emeralds—but more intense than that of natural Colombian emeralds—was observed in all cases. In some of the synthetic Lennix emeralds tested, the luminescence excited by cathode rays was different at the edges and within a narrow outer zone (red) from that seen in the interior (violet-blue or purple). No other emeralds (synthetic or natural) tested thus far have displayed the purple or bright violet-blue luminescence observed in the Lennix specimens.

X-Ray Diffraction Data. Microsamples (about 20–30 μm in diameter) were isolated by means of the MEA apparatus (Graziani, 1983), within both the deep green and the pale green zones of all the specimens. Subsequently, X-ray diffraction patterns were obtained using a Gandolfi camera (Gandolfi, 1967), and unit-cell parameters were estimated by a least-squares refinement of the diffraction data (Farinato and Loreto, 1975; De Angelis et al., 1977), indexed by comparison with those listed by JCPDS. The results for the light green areas were $\underline{a} = 9.203 \pm 0.002$ Å, $\underline{c} = 9.181 \pm 0.004$ Å; for the dark green areas, they were $\underline{a} = 9.202 \pm 0.003$ Å, $\underline{c} = 9.187 \pm 0.005$ Å.

X-ray Topography. Experiments were carried out on slabs of the synthetic Lennix emeralds cut perpendicular to the c-axis and polished by standard procedures (Scandale et al., 1979).

The tests were performed by means of a Lang camera, recorded on Ilford high-resolution plates, using $Mo_{K\alpha 1}$ radiation. The topography was remarkable in the contrasting features that covered the entire surface and permit reconstruction of the growth history of the examined crystal. In fact, the sample resulted from the aggregation of different smaller crystals around a subhexagonal central nucleus. This kind of growth is quite different from that of natural emeralds, in which the crystals grew during a slow cooling of the parent solution, and is thus typical of synthetic beryl grown in flux conditions.

Infrared Spectra. Infrared spectra in the range 4000 to 600 cm^{-1} were obtained on a Perkin Elmer 398 filter grating spectrometer, using 1 mg of beryl in 200-mg KBr discs. The bands at 3590 and 3694 cm^{-1} that are normally observed in natural emeralds seem to be totally absent, as would be expected for a flux-grown synthetic emerald (Flanigen et al., 1967), thus yielding another valuable means of distinction. However, infrared spectra in the same range that were obtained from polished slabs oriented parallel to the c-axis showed less distinct features.

TABLE 2. Results of the chemical analyses of the pale green and deep green areas of eight rough and one faceted Lennix synthetic emerald.[a]

Oxide	Pale green areas (wt.%)	Deep green areas (wt.%)
SiO_2	65.83	66.04
Al_2O_3	18.02	18.03
Cr_2O_3	0.57	1.19
FeO[b]	0.50	0.70
BeO	13.06	12.31
MgO	0.46	0.44
MnO	0.07	0.06
Na_2O	0.32	0.21
K_2O	0.14	0.14
H_2O CO_2	0.06	0.08
Total[c]	99.03	99.20

[a] *All oxides were determined by electron microprobe except: Be was determined by the pyrophosphate method, and H_2O plus CO_2 were determined thermogravimetrically. The results reported are average values.*

[b] *Total iron as FeO.*

[c] *The following elements were checked but not detected: Ti, V, Ca, Ba, Cs. Not recognized with spectrographic method: Li.*

Microscopic Examination of Inclusions. The Lennix synthetic emerald samples were examined with a gemological binocular microscope in transmitted light and under crossed polars. The specimens are characterized by a variety of inclusions that may generally be divided into five categories:

1. Opaque, tube-like inclusions aligned preferentially parallel to the c-axis (figures 2–4)
2. Clusters of inclusions along the borders of sequential growth zones that parallel the edges of the basal pinacoid (figure 5)
3. Slender, subhedral prismatic crystals of synthetic phenakite and beryl (figures 6–8)
4. Secondary flux-lined healed fractures that at low magnification look like "wispy veils" (figure 9)
5. Two-phase inclusions grouped along the edges of the basal pinacoid and sometimes parallel to the c-axis (figures 4 and 10)

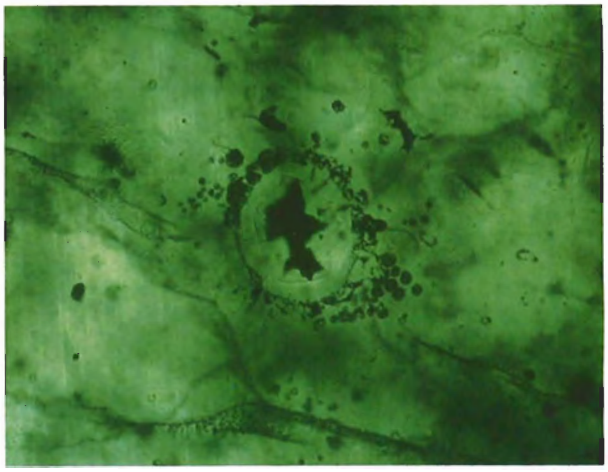


Figure 2. This partly flux-filled (MoO_3) tube-like inclusion in a Lennix synthetic emerald is surrounded by peripheral synthetic beryl crystals. A number of wispy veil-like inclusions characteristic of flux-grown synthetic emeralds are also evident. Transmitted light, magnified 30×.

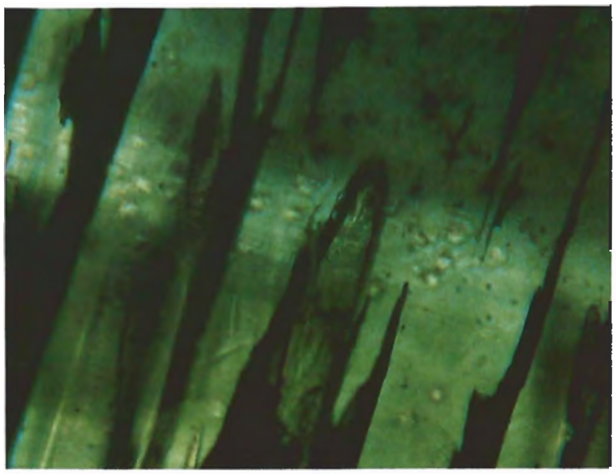


Figure 3. A different view of a number of tube-like inclusions similar to the one seen in figure 2 shows that they are oriented in channels that run parallel to the c-axis. Transmitted light, magnified 100×.

Figure 4. These irregular, opaque MoO_3 flux inclusions are accompanied by peripheral synthetic beryl crystallites and two-phase inclusions. Transmitted light, magnified 64×.

Figure 5. Color zones, representing the various stages of growth of the synthetic emerald, echo the hexagonal frame of the Lennix crystal growth. On this basal plane, a number of dichroic synthetic beryl crystals are evident. Transmitted light, magnified 10×.

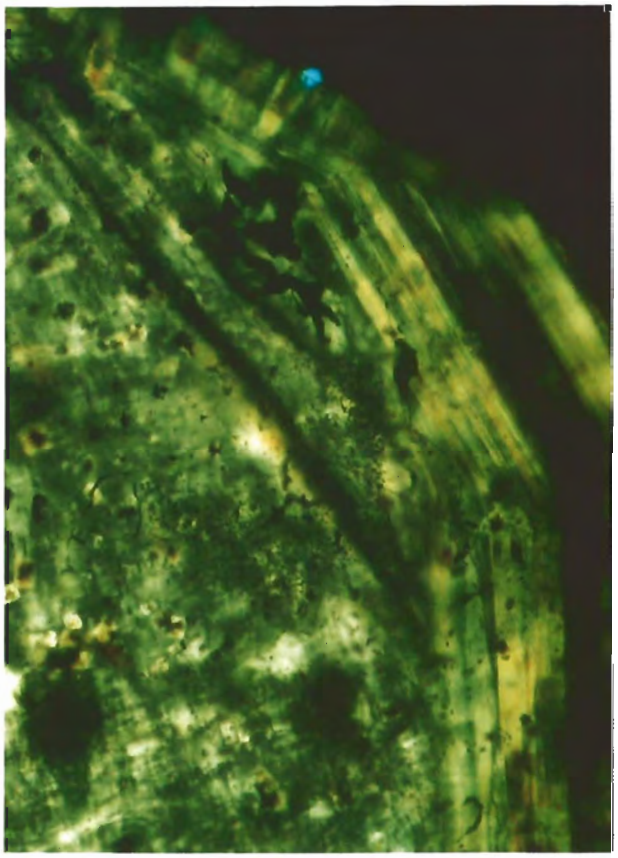


Figure 6. This spider-like configuration in a Lennix synthetic emerald proved to be a grouping of crystals of synthetic phenakite. Transmitted light, magnified 100×.

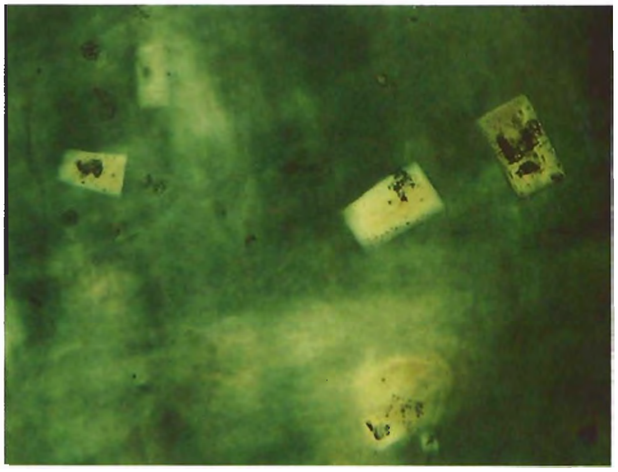


Figure 7. Individual crystals of synthetic beryl are observed at right angles to their c-axes in this Lennix synthetic emerald. Crossed polars, magnified 30×.

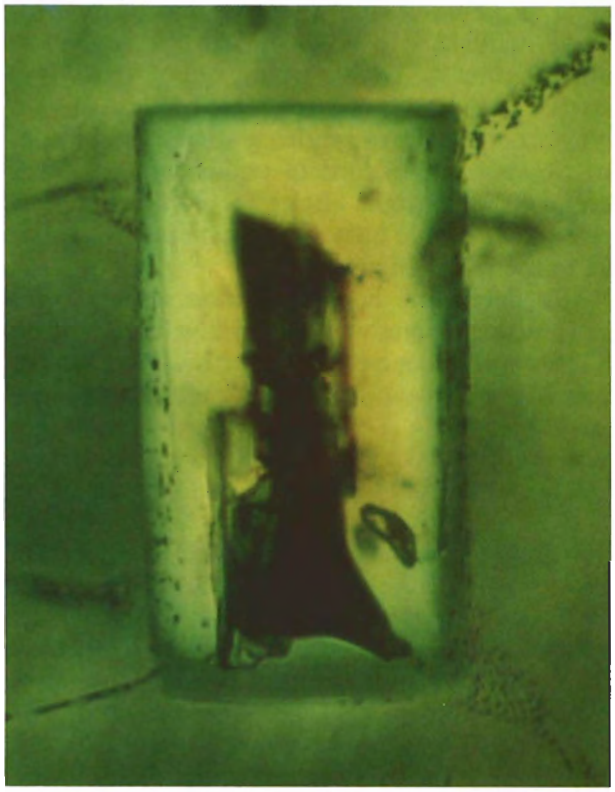
Opaque, Tube-like Inclusions. X-ray transmission micrographs were made on the opaque, tube-like inclusions oriented in channels (figures 2–4). These analyses identified subordinate crystals of synthetic beryl along the channel walls, and a thin film of flux which was opaque to X-ray microradiography. Chemical analysis of the flux proved it to be molybdenum oxide (MoO_3).

Growth Zoning and Associated Inclusions. Optical observations attest to the presence of various stages of crystal growth. Along the edges of these growth zones, two kinds of associated inclusions are evident: minute euhedral synthetic beryl crystals (figure 5) and clusters of synthetic phenakite. X-ray diffraction patterns identified the latter inclusions (JCPDS card no. 9-431). This identification was confirmed by microprobe analysis and subsequent stoichiometric elaboration of the chemical data.

Other Crystal Inclusions. The Lennix synthetic emerald also contains discrete, minute, acicular, prismatic crystals that sometimes consist of tri- and poly-angular associations (figure 6). The chemical composition of these inclusions is typical of phenakite and very similar to that of the clusters described previously.

Transparent subhedral prismatic crystals (approximately 0.05 × 0.03 mm) were also observed perpendicular to the c-axis of the synthetic host emerald. Not only are the refractive indices of these crystal inclusions similar to those of the synthetic host emerald, but microchemical analyses also revealed that they are similar in chemical composition to the host, particularly to the deep green zones (table 2). Consequently, these inclusions were determined to be synthetic beryl (figures 7 and 8).

Figure 8. An opaque black flux inclusion marks the center of this greatly enlarged synthetic beryl crystal in a Lennix synthetic emerald. Crossed polars, magnified 150×.



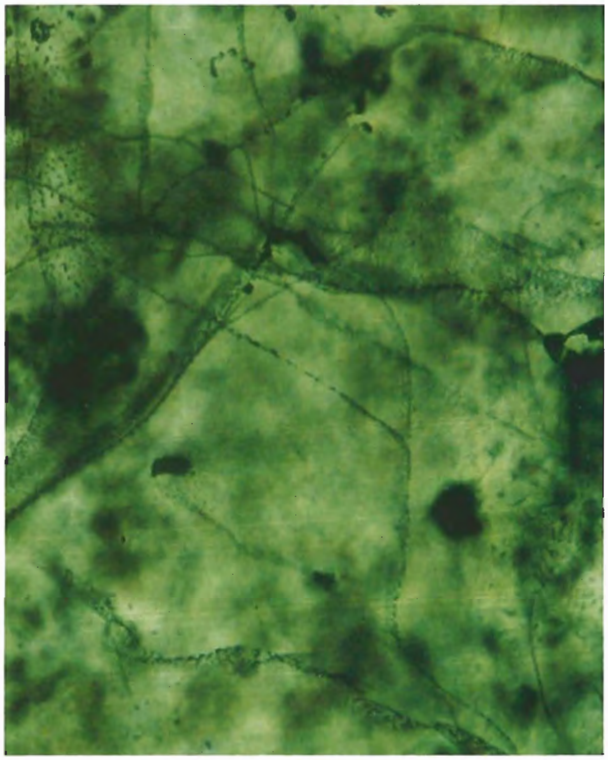


Figure 9. These delicate "wispy veils" are actually secondary flux-lined healed fractures in the Lennix synthetic emerald. Transmitted light, magnified 15×.

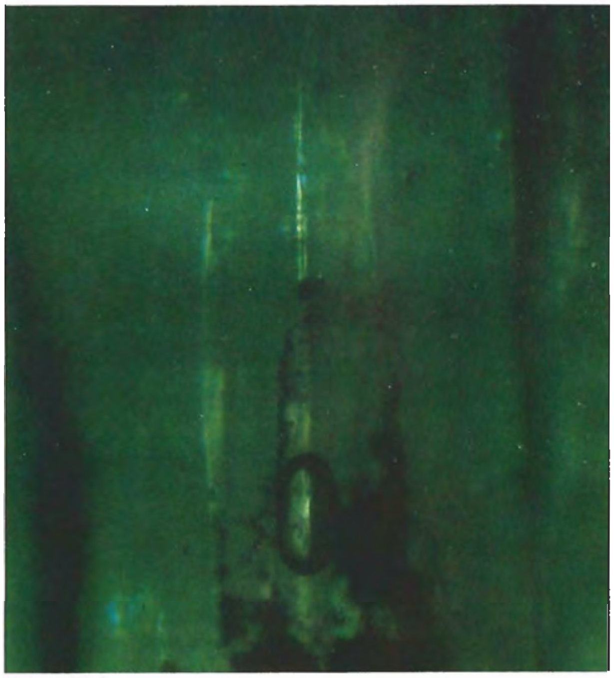


Figure 10. In this greatly enlarged two-phase inclusion, the large oval bubble that corroborates the second phase is probably in a glassy flux relic. The inclusion runs parallel to the c-axis of the host. Transmitted light, magnified 100×.

The whole crystal also contains many two-phase inclusions in wisp- or veil-like configurations (figure 9). These "wispy veils"—more precisely, secondary flux-lined healed fractures—are typical of flux-grown synthetic stones. In addition, small, sporadic swarms of two-phase inclusions occur either at right angles to the c-axis of the synthetic emerald host or, more frequently, parallel to the c-axis (figure 10).

To determine homogenization temperatures for these inclusions, we used a Nikon Optiphot Pol. XTP-11 microscope equipped with a Fluid Inc. gas flow heating/freezing system for temperatures up to 700°C and a Leitz 1350 device for higher temperatures. At least nine hours of isothermal heating were used for each run. Homogenization could not be observed up to 800°C.

Two-phase inclusions with internal crystallization products were sectioned by MEA for analysis. Optical investigations showed that the internal walls of these inclusions are covered by irregularly shaped crystals with a chemical composition very close to that of the synthetic host emerald.

These considerations suggest that, after the formation of the cavities and before their closure (sealing), beryl crystallization occurred. This phenomenon is very close to that described by Yermakov (1965) as a deposition of the cognate substance on the inclusion wall.

CONCLUSION

For the gemologist, the very fact that the Lennix synthetic emeralds are so heavily included can cause problems, because they superficially resemble poor-quality natural emeralds. If, however, wispy veil-like partially healed fractures (similar to those shown in figure 9) are present, then regardless of the other inclusions (which may somewhat resemble those seen in natural emeralds), the stone can be identified as synthetic. The low refractive-index and specific-gravity values are also indicative of flux-grown synthetic emeralds; when these are obtained in conjunction with the observation of "wispy veils," they conclusively prove synthesis.

Where available, more sophisticated chemical analyses, infrared spectra, and cathodoluminescence experiments all provide effective means of differentiating the Lennix synthetic emerald from both natural emeralds and other synthetic emeralds.

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NOTES
· AND ·
NEW TECHNIQUES

SYNTHETIC OR IMITATION? AN INVESTIGATION OF THE PRODUCTS OF KYOCERA CORPORATION THAT SHOW PLAY-OF-COLOR

By Karl Schmetzer and Ulrich Henn

The products of Kyocera Corp. that show play-of-color were investigated to determine if the materials are truly synthetic opal or rather are opal simulants. The authors propose that, because these materials contain no water, they do not match the composition of natural opals and, thus, should be designated opal simulants. The gemological properties of the samples examined are also provided, including those by which the Inamori material can be separated from natural opal.

Gem materials showing play-of-color are manufactured in Japan by Kyocera Corp. and sold under the trade name Inamori Created Opals (figure 1). The first gemological reference to these materials was by Fryer et al. (1983); in this short note, the samples were accepted as being synthetic opal, as stated by the manufacturer, entirely on the basis of their gemological properties. However, it has been suggested by one of the present authors and his coworkers that for non-single-crystal synthetics it is necessary to determine both the chemical composition ($SiO_2 \cdot nH_2O$ for opal) and the phases present. Only when a man-made gem material is essentially, if not absolutely, identical in these respects to the natural gemstone is it acceptable as a synthetic counterpart.

A working definition for a distinction of true synthetic gem materials from imitations was proposed by Nassau (1976, 1977). This proposal included observations at five different magnifications ranging from the atomic level to inspection by the naked eye. It also included the following four criteria on the basis of which man-made gem materials must be essentially identical to their natural counterparts to be labeled *synthetic*: (1) chemical composition, (2) crystal structure, (3) submicroscopic structures, and (4) appearance to the naked eye. These criteria have been applied in discussions of non-single-crystal materials such as man-made turquoise (Schmetzer and Bank, 1980, 1981; Lind et al., 1983a and b), man-made opal (Schmetzer, 1983a, 1984), and man-made lapis lazuli (Schmetzer, 1983b, 1985).

In the case of the products of Gilson that show play-of-color, the man-made materials do not match natural opals in chemical composition, primarily because of the absence of distinct amounts of water. Thus, in the opinion of the authors, these substances should be designated

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Figure 1. These three examples of Inamori Created Opal are produced by the Kyocera Corp. of Kyoto, Japan. The sample with the black body color weighs 3.96 ct and measures 10 × 12 mm. Photo © Tino Hammid.

opal simulants rather than synthetic opals (Schmetzer, 1983a, 1984). The present study was conducted in an attempt to clarify the nomenclature for the man-made products of Kyocera Corp. that are known as Inamori Created Opals in the trade and have been represented as synthetics.

MATERIALS AND METHODS

Gemological properties were determined on several samples of the Kyocera product; on the basis of these tests, play-of-color, and body color, four types were identified (see table 1), with two to four samples of each type selected for additional testing. Structure was then determined by X-ray diffraction analyses with a Debye-Scherrer camera; semiquantitative chemical investigations were carried out using the energy-dispersive analytical system of an ARL-SEMQ electron microscope. Thermogravimetric analyses were undertaken between 20° and 1000°C by means of a DuPont thermobalance.

GEMOLOGICAL PROPERTIES

Visual appearance, refractive-index values, and specific-gravity values of the samples investigated are given in table 1. The refractive indices of the white and colorless (body color) samples were found to be close to the upper limit, but still within the range, for natural opals; the refractive indices of the black samples were found to be

TABLE 1. Gemological properties of the man-made products of Kyocera Corp. that show play-of-color.

Sample types[a]	Body color	Play-of-color	Refractive index[b]	Specific gravity[b]
A	Colorless	Green, blue, violet	1.459–1.460	2.20–2.22
B	White	Green, blue violet	1.460	2.21–2.22
C	Black	All spectral colors	1.463	2.23
D	Black	Green, blue, violet	1.466	2.24

[a] *Two to four samples of each type were tested.*
[b] *Ranges are for different samples of the respective type.*

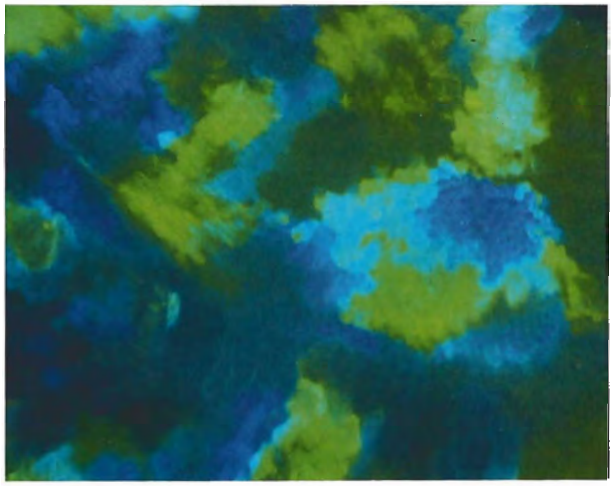
slightly higher than the highest values determined to date for natural opals (Frondel, 1962; Deer et al., 1963; Tröger, 1971; Phillips and Griffen, 1981). For all of the samples, the specific gravity determined slightly exceeds that of natural opals.

The refractive-index and specific-gravity values for the Inamori products are distinctly higher than the values for the Gilson products, which lie in the range of about 1.440 and 2.04, respectively (e.g., Eppler, 1974; Scarratt, 1976). However, when viewed with a microscope, the Inamori products show features that also appear in the Gilson material. Specifically, the Inamori cabochons reveal a diagnostic columnar structure that is evident when the samples are viewed at various angles to the curved surface of the cabochons (figure 2). Perpendicular to this columnar structure are mosaic-like patterns with distinct boundaries between different "grains." Each "grain" is divided into several "subgrains." In gemology, this pattern is often referred to as a "lizard-skin, "chicken-wire," or "honeycomb" structure (figure 3). Although this pattern has been observed in a few natural opals (Scarratt, 1986), it is usually considered characteristic of opal imitations.

All of these properties are consistent with the data provided by Fryer et al. (1983) and are considered to be of diagnostic value. In most cases, a combination of microscopic examination with determination of refractive index and specific gravity is sufficient to distinguish the Inamori product from natural opals.

Figure 2. The columnar structure of the color "grains" is evident in this Kyocera opal imitation with black body color. Magnified 20×.

Figure 3. This Kyocera opal imitation with black body color shows the mosaic-like patterns with distinct boundaries between different "grains," as well as the pattern referred to as "lizard-skin," "chicken-wire," or "honeycomb" that is caused by the subdivision of each color "grain." This pattern is considered characteristic of man-made opal. Magnified 40×.



COMPOSITION

X-ray powder diffraction analyses of the samples selected for detailed examination revealed no distinct pattern; that is, all four types are amorphous to X-rays. Chemical investigations indicate silica as the dominant component; no other major constituents were detected (as is also typical of most natural opal). Thermogravimetric analyses of all the samples showed no loss of weight up to 1000°C (see figure 4, which also includes a typical dehydration curve for natural opal from Australia). These results indicate that no water is present in any of the samples of Kyocera material that were tested.

CONCLUSIONS

The products of Kyocera Corp. that show play-of-color consist of amorphous silica glass without any admixtures of water. Comparison with the properties of lechatelierite, an amorphous and anhydrous form of silicon (R.I. = 1.46, S.G. = 2.2) further supports this conclusion. Because of the complete absence of water, these man-made materials are not within the compositional range of natural opals (see, e.g., Schmetzer, 1984). Consequently, the authors propose that these products of Kyocera Corp. should be designated opal simulants rather than synthetic opals. It is not sufficient that in both natural opals and (as determined by the authors) the Kyocera opal imitations the play-of-color is caused by a closely packed array of uniformly sized amorphous silica spheres. In the opinion of the authors, a true synthetic must be essentially identical in structure and composition to its natural counterpart.

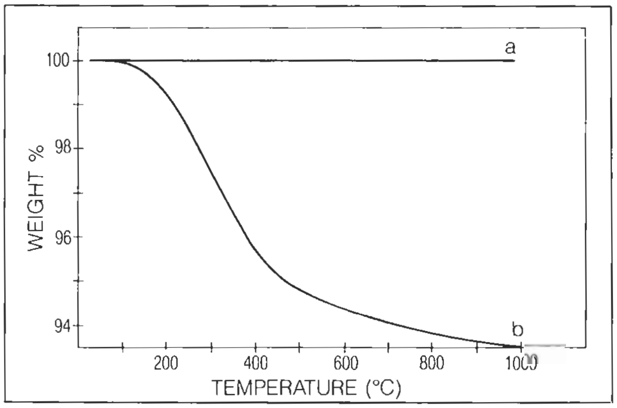


Figure 4. The absence of water in the Kyocera opal imitation is evident in this comparison of the curve produced by thermogravimetric analysis for a sample of the man-made material with black body color (a) with that of one produced for a natural Australian opal of white body color (b).

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MAN-MADE JEWELRY MALACHITE

By V. S. Balitsky, T. M. Bublikova, S. L. Sorokina, L. V. Balitskaya, and A. S. Shteinberg

Jewelry-quality synthetic malachite is now being manufactured in the USSR. The texture, structure, and physical and physico-chemical properties of this synthetic malachite are reported. Three textural types have been identified: banded, silky, and bud-like. The malachite is composed of closely adjacent spherulitic aggregates, the generation and growth of which are controlled by the crystallization conditions. In chemistry, color, density, hardness, optical properties, and X-ray diffraction, the synthetic malachite proved virtually identical to the natural material. Only in the thermograms were significant differences noted. Therefore, the man-made malachite holds much promise for use in stone cutting and the jewelry trade.

One of the major advances in gemstone synthesis over the past few years has been the production of jewelry-quality synthetic malachite. The synthesis was accomplished at three institutions in the USSR at approximately the same time: Leningrad State University (LGU; Petrov et al., 1985); the All-Union Institute for the Synthesis of Mineral Raw Materials (VNIISIMS), in the Ministry of Geology of the USSR (Balitsky, 1983; Timokhina et al., 1983); and the Institute for Experimental Mineralogy (IEM, USSR Academy of Sciences; Balitsky et al., 1985). These institutions have devised several original methods which allow nearly all textural varieties found in natural malachite to be synthesized under chosen conditions (figures 1–5).

The methods currently used to synthesize malachite are based on its crystallization from aqueous solutions. Specimens produced thus far range from 0.5 kg to several kilograms. At the international exhibition held during the 27th International Geological Congress (Moscow, 1984), vases cut from synthetic malachite pillars weighing as much as 8 kg (and manufactured at the VNIISIMS) were on display. In fact, synthetic malachite is now being produced on a commercial level. For example, the "Uralskije samotsvety" plant (at Sverdlovsk, in the Urals) both produces synthetic malachite and mounts it in a wide variety of jewelry (Petrov et al., 1985). The authors do not know if this material is being distributed outside the Soviet Union.

This article briefly describes the three most attractive varieties of the jewelry-quality synthetic malachite produced using the methods of the present authors (Balitsky, 1983; Balitsky et al., 1985): banded, silky, and bud-like. The authors then discuss the properties of the synthetic malachite and tests conducted to see how it can be separated from the natural material.

MAJOR TYPES OF SYNTHETIC MALACHITE

Banded. The banded synthetic malachite is very similar in appearance to the malachite from Zaire. Banding is formed by alternating parallel zones that range in color from light to very dark green, almost black. The width of the zones varies from a few tenths of a millimeter to 3–4 mm. The zone boundaries are straight, weakly undulating (see figure 2), or intricately curved. The bulk of the sample is composed of closely adjoining spherulitic aggregates of acicular or plate-like crystals. Both the spherulites and the crystals of which they are made become larger as a result of geometric selection during growth. The samples with contrast banding display recurrent (multilayer) generation of spherulites at the boundaries of particular zones. Where the banding is less contrasting, the development of new zones involves no interruptions in the formation of spherulites. Rather, in this case the spherulite crystals acquire a subparallel orientation (figure 3).

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Figure 1. These samples of synthetic jewelry-quality malachite, representing a mixture of banded and bud-like types, strongly resemble their natural counterparts. The largest specimen shown here is 100 × 90 mm.

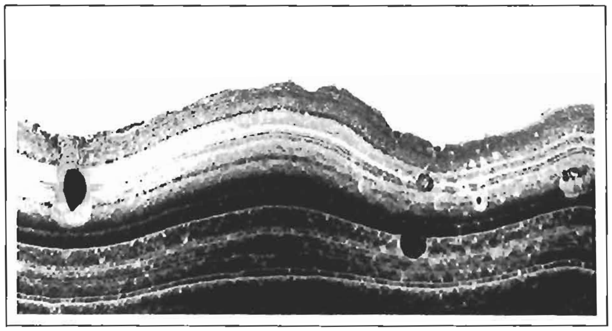

Figure 2. Undulating growth boundaries can be seen in this section of synthetic malachite with the banded texture. The cut is parallel to the growth direction. Maximum length and width, 100 × 28 mm.

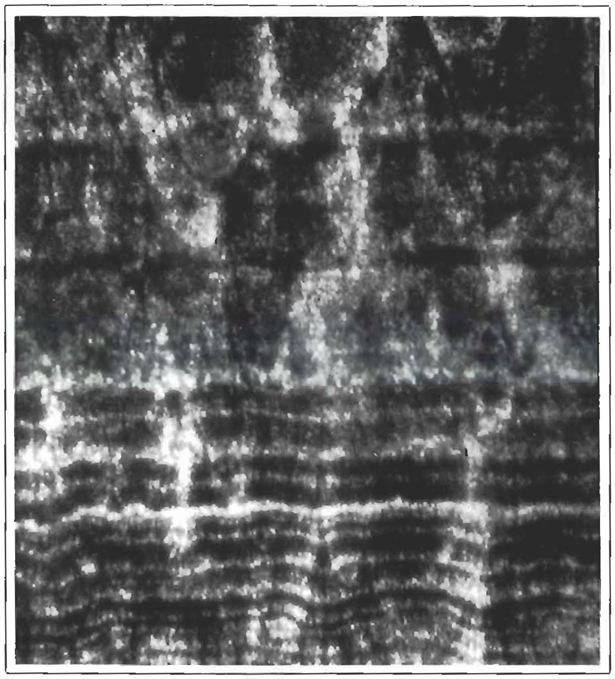

Figure 3. This finely banded sample of synthetic malachite shows the many-tier nucleation of spherulites. The cut is parallel to the growth direction. Magnified 30×.

Silky. When cut parallel to the growth direction, banded synthetic malachite displays chatoyancy and appears silky. Individual crystals in the silky aggregates are 0.01–0.1 mm thick and several millimeters long. In some samples with complex banding, the chatoyancy is particularly attractive. Distinct areas appear light in cuts parallel to the crystal elongation and almost black in cuts per-

Figure 4. A bud-like texture is evident in this sample of synthetic malachite, which is cut parallel to the growth direction. Maximum length and width, 30 × 12 mm.

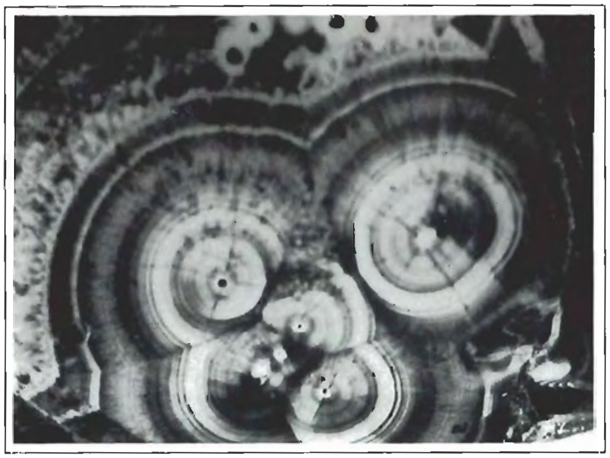

Figure 5. In this close-up view of a sample of bud-like synthetic malachite, the concentric zones of which the buds are comprised are readily evident. The cut is perpendicular to the growth direction. The buds range in diameter from 5 to 10 mm.

pendicular to it. The silky material is, however, the least desirable for jewelry use.

Bud-like. The bud-like synthetic malachite is of a higher jewelry quality than the banded material (see figure 4). It is similar in appearance to the famous Ural malachite. Individual buds in synthetic specimens range from 2–5 to 10–15 mm across. They are formed as a result of the growth of particular spherulites and develop either a radiated or a concentric zonal structure. In the former type, the crystals in the buds are arranged radially relative to the center of the spherulite nucleus. On cut surfaces, such buds display a gradual color change from almost black at the center to light green toward the edges. The coloration depends on the pattern of relative orientation of the crystal axis and the cut plane. In addition, the tones and intensity of the color can vary with the viewing angle or with the angle of light incidence.

In the second type of structure, the buds are composed of concentric zones that vary in color from light to dark green (figures 4 and 5). Each zone has the spherulitic structure, the spherulites being 0.01–3 mm in size. The zones composed of small spherulites are lighter than those composed of large ones. Every new zone normally gives rise to a new generation of spherulites, but occasionally earlier spherulites are inherited by the later ones.

In addition to the above textural types, several intermediate varieties of synthetic malachite—representing a mixture of two or all three of these types—are also possible (again, see figure 1).

PROPERTIES OF SYNTHETIC MALACHITE

The chemical composition (table 1) and principal physical and physico-chemical properties (table 2) of the scores of synthetic malachite samples examined for this study were compared with the data available on natural samples from the Urals, Ka-

TABLE 1. Mean chemical compositions for natural and synthetic malachite.[a]

Components (wt.%)	Natural (locality)	Synthetic (mfr.)	
	Kazakhstan	IEM[b]	VNIISIMS
CuO	71.77	70.22	71.90
MgO	0.001	0.017	nd[c]
CaO	0.003	0.014	nd
H_2O	8.52	9.31	—
CO_2	19.65	19.94	—
$H_2O + CO_2$	—	—	28.35
Total	99.94	99.50	100.25

[a] At least 20 samples of each type were analyzed. All analyses were performed by the authors using a combination of wet chemical and spectrophotometric methods.

[b] For the samples from Kazakhstan and IEM, FeO, SiO_2, TiO_2, Al_2O_3, and Fe_2O_3 were also determined but not detected.

[c] nd = not determined.

TABLE 2. Gemological properties of natural and synthetic malachite.[a]

	Natural (locality)		Synthetic (mfr.)		
Property	Zaire	Kazakhstan	IEM	LGU	VNIISIMS
Color	Light green to dark green	Green	Light green to dark green	Almost black to light green with pale bluish tint	Almost black to light green
Refractive indices					
α	1.907	1.909	1.908	1.907	1.911
β	1.874	1.875	1.876	1.875	1.877
γ	1.653	1.655	1.657	1.654	1.658
Density, g/cm^3	4.0	4.1	4.0	3.95	3.90
Hardness (Mohs scale)	4.4	4.2	4.2	4.5	3.5
Endothermal effect, °C (peak center)	342	340	270, 300	272, 301	275, 305

[a] *At least five samples of each type were examined.*

zakhstan, and Zaire (Grigorjev, 1953; Vertushkov, 1975). The chemical composition of the synthetic malachite produced by IEM and VNIISIMS proved almost identical to that of the natural malachite found at Kazakhstan (table 1), although some natural malachite has a high cobalt and nickel content (Deliens et al., 1973; Tarte and Deliens, 1974). Both the natural and the synthetic malachite examined contained minor amounts (hundredths and thousandths of a percent) of impurities such as zinc, iron, silica, sulfur, calcium, and phosphorus. These impurities had only a very slight effect on the refractive indices of the synthetic malachite, which average α = 1.909 ± 0.002, β = 1.876 ± 0.001, γ = 1.656 ± 0.002.

The synthetic malachite was found to vary in density (as determined hydrostatically) from 3.9 to 4.0 g/cm^3, and in hardness from 3.5 to 4.5 on the Mohs scale. The hardness is a little lower along the crystal elongation than perpendicular to it.

X-ray diffraction analysis of all the types of synthetic malachite produced thus far (DRON-2 diffractometer, CoK$_\alpha$ radiation, filter Fe) detected no differences from natural malachite (figure 6).

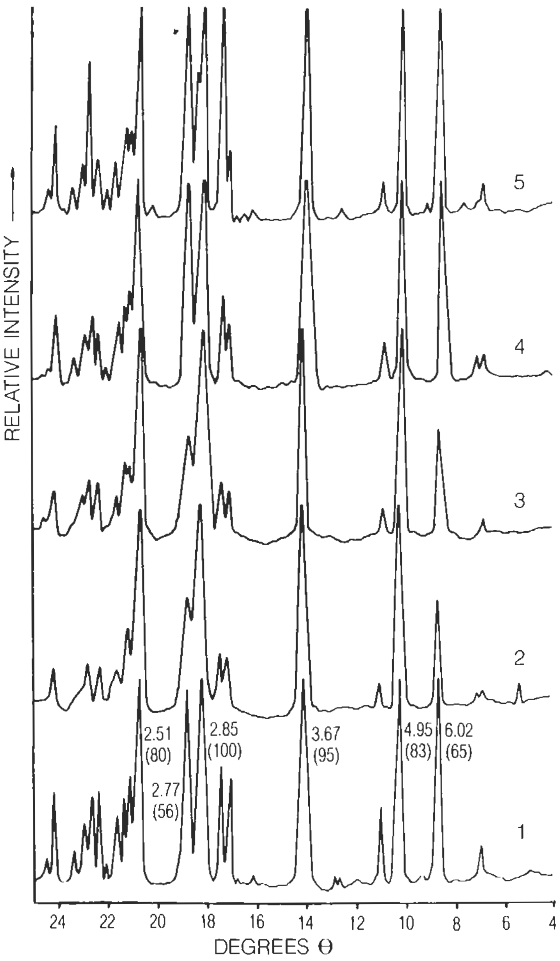

Figure 6. No significant differences were observed in the X-ray powder diffraction curves of natural and synthetic malachite. Natural samples: 1—Kazakhstan, 2—Zaire. Synthetic samples: 3—IEM, 4—LGU, 5—VNIISIMS.

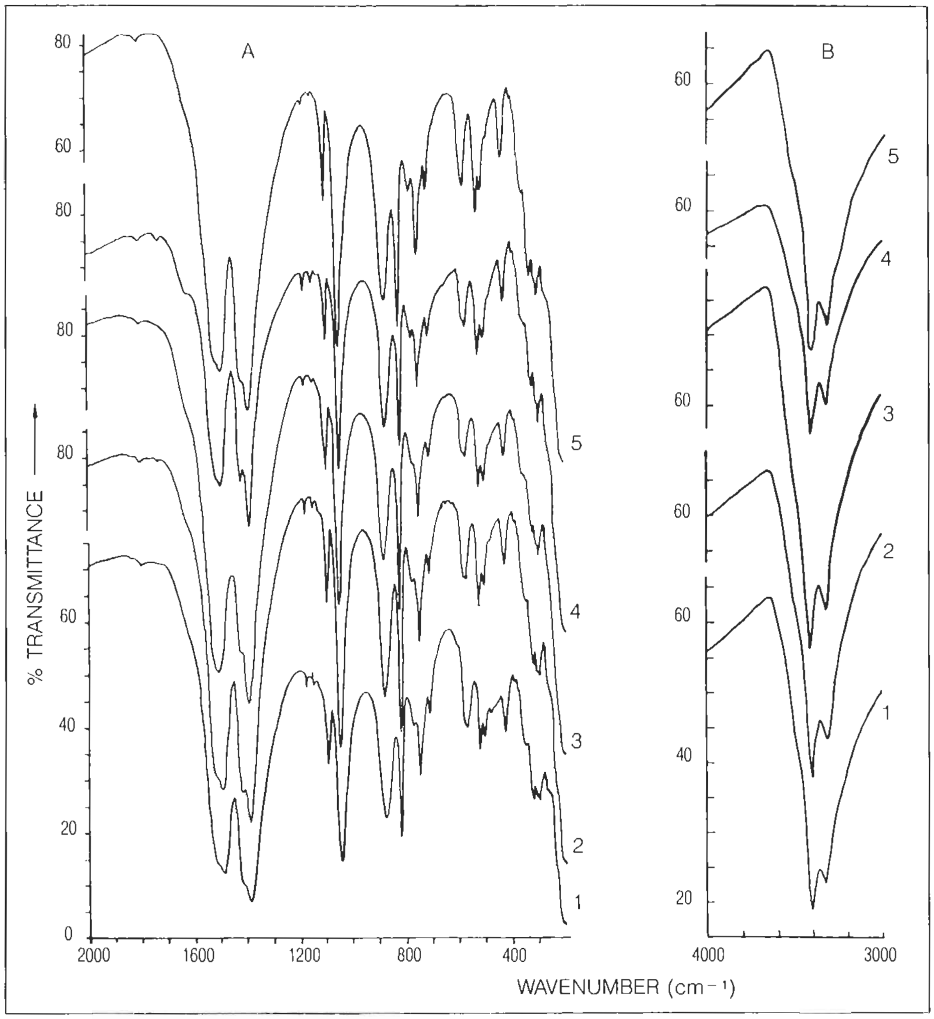

Figure 7. Examination of the infrared spectra of natural and synthetic malachite in the regions A = *200–2000 cm^{-1} and* B = *3000–4000 cm^{-1} revealed no significant differences either. Natural samples: 1—Kazakhstan, 2—Zaire. Synthetic samples: 3—IEM, 4—LGU, 5—VNIISIMS.*

As reported in 1983 by Timokhina et al., no differences in infrared spectra have been found for synthetic and natural malachite [either in the regions of stretching vibrations of Cu-O (400–600 cm^{-1}), C-O (1000–1100 and 1350–1550 cm^{-1}), and OH$^-$ groups (3315–3410 cm^{-1}), or in the deformation vibration region O-C-O (700–900 cm^{-1})]. Figure 7 shows characteristic infrared spectra in the regions 200–2000 cm^{-1} and 3000–4000 cm^{-1} for different samples of natural and synthetic malachite.

Some difference between synthetic and natural malachite can be seen in the pattern of curves produced by differential thermal analysis and thermogravimetry (figure 8). Five samples of each were tested. As illustrated in figure 8, dehydration and decarbonation of natural malachite take place at one stage marked by a profound endothermal effect in the 310°–390°C range (the peak centers at 340°–345°C) and at a weight loss of 27.5–28 mass %. In the synthetic malachite (the banded

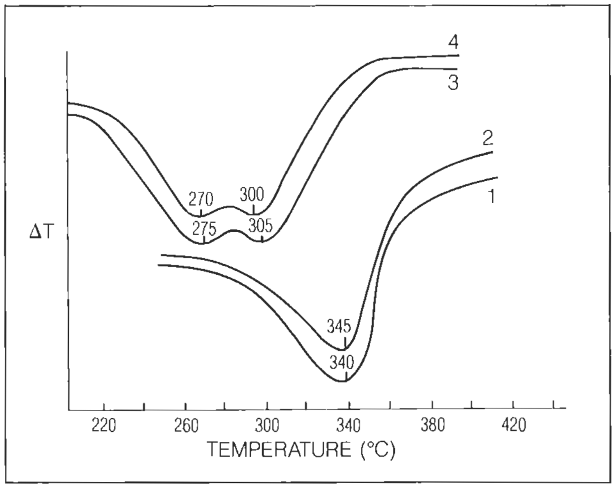

Figure 8. Only the thermograms revealed a clear distinction between the natural and synthetic malachite examined. Natural malachite from Kazakhstan (1) and the Urals (2); synthetic malachite with the banded (3) and bud-like (4) textures.

Figure 9. All of these polished samples of synthetic malachite show potential for use in jewelry, carving, or inlay. The cabochons range from 15 to 32 mm.

and bud-like varieties), the endothermal effect is displayed in a lower region, 230°–340°C, and the weight loss is 29–30 mass %. The thermograms of all the synthetic malachite tested always showed two weak minima (the first peak center is at 270°–275°C; the second is at 300°–305°C). The cause of these differences has not yet been determined. However, it does not appear that these differences have affected the mineral structure in any way.

CONCLUSION

The synthetic malachite currently being produced in the USSR is virtually a complete analogue of natural jewelry-quality malachite with respect to physical appearance, chemistry, texture, structure, and principal physical properties (again, see table 2). Thus far, the only method that has proved effective in separating the natural from the synthetic material is differential thermal analysis. However, the fact that this test is destructive makes it impractical for gemological purposes. It appears, therefore, that there are unlimited possibilities for the man-made malachite to be used in stone cutting and for inlay, carvings, and cabochons in the jewelry trade (figure 9).

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INAMORI SYNTHETIC CAT'S-EYE ALEXANDRITE

By Robert E. Kane

The world's first commercially available synthetic cat's-eye alexandrite chrysoberyl is now being manufactured and marketed by the Kyocera Corporation in Kyoto, Japan. Kyocera markets synthetic gemstones in the United States under the trade name "Inamori Created." This article reports on a detailed gemological examination of this new synthetic cat's-eye alexandrite. Although most of the gemological properties of this new synthetic overlap those of natural cat's-eye alexandrite, it can be identified by its unique internal characteristics and its unusual fluorescence to short-wave ultraviolet radiation.

In late January 1987, the Inamori Jewelry Division of Kyocera International, Inc., San Diego, California, gave GIA two synthetic cat's-eye alexandrite chrysoberyls for study. Kyocera reported that these two oval double cabochons (3.27 and 3.31 ct) were representative of the new synthetic cat's-eye alexandrite being manufactured and cut in their highly automated synthetics facility in Kyoto, Japan. (figure 1).

This new synthetic cat's-eye alexandrite was first marketed in Japan set in jewelry in early September 1986, and has just been released in the United States as loose stones as well as in jewelry. As of June 1987, Kyocera had produced only 250 ct of this material for jewelry purposes. The stones currently available range in weight from slightly under 1 ct to 7.5 ct (K. Takada, pers. comm., 1987). They are marketed in the U.S. under the trade name "Inamori Created," as are Kyocera's other synthetic gems. In preparing this article, a total of 13 cabochon-cut Inamori synthetic cat's-eye alexandrites, ranging in weight from 1.04 to 3.31 ct, were subjected to several gemological tests, including detailed microscopic study. The results are reported below. A brief history of chrysoberyl synthesis is also provided.

HISTORY OF CHRYSOBERYL SYNTHESIS

Alexandrite is the color-change variety of chrysoberyl, the beryllium aluminate, $BeAl_2O_4$, with an impurity of Cr^{3+}. A conspicuous change of color from an intense bluish green to a deep "raspberry" (purplish) red is the most desirable for alexandrite. The flux growth of nonphenomenal chrysoberyl dates back to the latter half of the 19th century. From 1845 on, Ebelman used borate fluxes to synthesize very small crystals of chrysoberyl. Later Deville and Caron, and Hautefeuille and Perrey, also reported similar success with chrysoberyl synthesis (Nassau, 1980). Nassau also noted that in recent years experiments have been conducted with the more common lithium molybdate and lead oxide–lead fluoride–boron oxide flux combinations, but only small crystals have been produced. He also cites reports of the use of the Verneuil process to synthesize chrysoberyl or alexandrite-crystal boules.

Synthetic chrysoberyl containing only chromium as a trace element, usually at the 0.05% level or less (which results in pale color and a very weak alexandrite effect), provides a useful laser crystal. Laser rods up to 2.5 cm in diameter and 15 cm long (1 in. × 6 in.) are being grown by the Czochralski pulling technique at the Allied Chemical Corp. of Morris Township, New Jersey (Morris and Cline, 1976). Faceted stones cut from synthetic alexandrite grown by the Czochralski method at Allied Signal Corp. (formerly Allied Chemical) are now commercially available in the trade. The hydrothermal growth of synthetic chrysoberyl, but apparently not of alexandrite, has been reported in a series of Czechoslovakian patents by D. Rykl and J. Bauer (Nassau, 1980).

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Faceted synthetic alexandrite has been produced and marketed sporadically since 1973 by Creative Crystals of San Ramon, California, under the trade name Alexandria-Created Alexandrite (Cline and Patterson, 1975). Although both flux and melt techniques are covered in this patent, the inclusions present in the synthetic alexandrite commercially available from Creative Crystals indicate that this material is definitely flux-grown. In 1974, Creative Crystals experimentally synthesized cat's-eye chrysoberyl (not alexandrite) by the flux method; however, this product was never placed on the market (D. Patterson, pers. comm., 1987).

Faceted synthetic alexandrite has been commercially available from Kyocera International since 1975 (K. Takada, pers. comm., 1987). This material does not show any characteristics of flux growth and is probably grown by a melt process, specifically the Czochralski pulling method. Confirmation of this is provided by a U.S. patent assigned to Kyoto Ceramic Co. by Machida and Yoshihara (1980), in which the primary emphasis is a description of synthesizing alexandrite by a direct melting method: the Czochralski (rotational pull-up) technique.

On July 15, 1983, *Women's Wear Daily* reported that the Sumitomo Cement Company's central research laboratory, based in Funabashi City, Japan, had succeeded in synthesizing cat's-eye alexandrite. Sumitomo filed for worldwide patents for synthesizing this material with a melt method that uses the floating-zone technique (K. Takada, pers. comm., 1987). The growth process is followed by spontaneous cooling to room temperature and a special heat-treatment process.

In September 1983, independent of Sumitomo, Kyocera began experimentation on the synthesis of cat's-eye alexandrite (K. Takada, pers. comm., 1987). This research led to the eventual commercial marketing of this new synthetic. In a U.S. patent by Uji and Nakata (1986) assigned to the Kyocera Corp., the synthesis of single-crystal cat's-eye chrysoberyl (not alexandrite) is described. The primary emphasis of the patent is on several examples whereby the Czochralski method is used. The patent also mentions two different examples of synthesizing an "olive-green" and a brown cat's-eye chrysoberyl (not alexandrite) by means of a lithium molybdate flux. However, information contained in this patent, in addition to the fact that the Inamori synthetic cat's-eye alexandrites do not show any microscopic characteristics of flux growth, leads to the conclusion that this new product is grown by the Czochralski method.

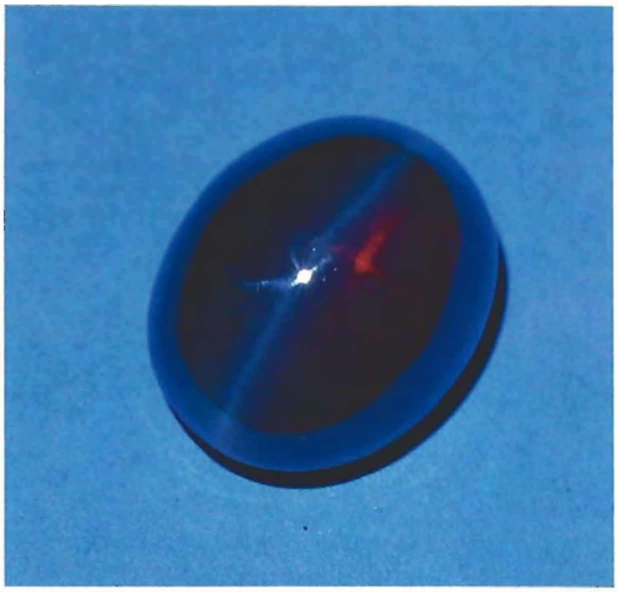
Figure 1. This Inamori synthetic cat's-eye alexandrite appears dark purple-red in incandescent light. Photo © Tino Hammid.

GEMOLOGICAL PROPERTIES

Thirteen cabochon-cut Inamori synthetic cat's-eye alexandrites were closely examined and submitted to a variety of gemological tests. The results are reported below and summarized in table 1.

Visual Appearance. A distinct color change was observed in all of the samples in fluorescent illumination (or natural sunlight) as compared to incandescent illumination. When the stones were viewed with a single overhead light source, a broad eye of moderate intensity was noted in each. When viewed with a Verilux fluorescent light source, the synthetic cat's-eye alexandrites appear dark grayish green with a slightly purplish overtone. The eye exhibits a slightly greenish white-blue color. There is an overall dull, "oily" appearance. When viewed with an incandescent light source (figure 1), the same stones changed to a dark purple-red with a bluish white eye, again with an overall dull, "oily" appearance. This "oily" appearance affected the transparency slightly in both types of illumination. When viewed with the unaided eye and overhead illumination, as well as with transmitted illumination, these synthetics appeared to be completely free of inclusions.

TABLE 1. The gemological properties of the Inamori synthetic cat's-eye alexandrites.

Properties that overlap those of natural cat's-eye alexandrites	
Color	Moderate to distinct color change from dark grayish green, with a slight purplish overtone, and a slightly greenish white-blue eye under fluorescent lighting; to a dark purple-red, with a bluish white eye when viewed with incandescent light
Visual appearance to the unaided eye	Transparent with an overall hazy, "oily" appearance in both lighting conditions; no inclusions are visible to the unaided eye
Refractive index	Spot readings of 1.745–1.755
Trichroism	Strongly distinct colors of purple-red, brownish orange, and gray-green
Color filter reaction	Bright red
Specific gravity	3.73 ± 0.02; estimated with heavy liquids
Absorption spectrum[a] (400–700 nm)	Absorption lines at 680.5, 678.5, 665, 655, 645, 472, and sometimes at 468 nm (very weak); broad absorption blocking out all of the violet and some of the blue, and portions of the yellow-green to orange areas of the visible spectrum. Spectrum will vary depending on viewing position and which rays are isolated.
Key identifying properties	
Fluorescence	
Long-wave	Moderate red (overlaps natural, *not diagnostic)*
Short-wave	Weak, opaque, chalky yellow fluorescence that appears to be confined near the surface; careful examination reveals an underlying weak red-orange fluorescence.
Inclusions	Parallel, straight-appearing and undulating color-zoned growth features; and nondescript white-appearing, minute particles specifically oriented in parallel planes (visible only with fiber-optic illumination), which give rise to the chatoyancy. With the iris diaphragm partially closed (over darkfield illumination at 25×) to create a shadowing effect, the unevenly spaced parallel growth features become more evident and reveal themselves as undulating rather than straight.

[a] *As observed through a hand-held type of spectroscope.*

Interestingly, when the cabochons were viewed under a strong, single incandescent light source down the long direction, asterism was observed. The two additional rays were weaker than the chatoyant band. This behavior would not be expected in natural cat's-eye alexandrites.

Physical and Optical Properties. Testing of the Inamori synthetic cat's-eye alexandrites revealed refractive-index values (1.745–1.755, obtained by the spot method), specific-gravity values (3.73 ± 0.02), trichroism (purple-red, brownish orange, and gray-green), and a bright red reaction to the Chelsea color filter that are all essentially consistent with the corresponding properties in natural cat's-eye alexandrite. The spectra observed with a GIA Gem Instruments spectroscope unit are the same as those for alexandrite (natural and synthetic) described in Liddicoat (1981, p. 191) and shown here in figure 2. These features were confirmed by spectrophotometry.

Transmission Luminescence. When the synthetic cat's-eye alexandrites were placed over the strong light source from the opening of the iris diaphragm on the spectroscope unit, they all displayed a very strong greenish white transmission luminescence (in some viewing positions a slight pink cast was seen; see figure 3, left). In fact, the transmission luminescence was so strong that it was visible even in sunlight, or any artificial light. This transmission luminescence is the cause of the overall dull, "oily" appearance seen when the stones are viewed with the unaided eye, as discussed above.

Although natural cat's-eye alexandrites may exhibit a similar transmission, it is generally not as strong and has a slightly different appearance. In contrast, many natural as well as synthetic alexandrites (not chatoyant) will exhibit a strong red transmission (see figure 3, right).

Figure 2. The absorption spectra for Inamori synthetic cat's-eye alexandrite, as observed on a hand-held type of spectroscope at room temperature. The upper drawing shows the spectrum seen in the red direction, and the lower shows the spectrum seen in the green direction. Spectral colors are approximate.

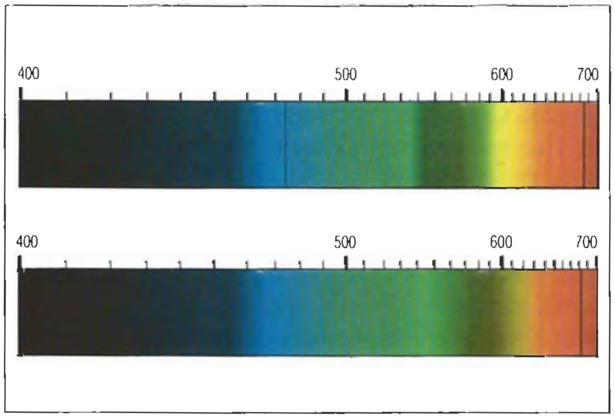

Figure 3. Transmission luminescence as seen over the strong light source from the opening of the iris diaphragm on the spectroscope unit. Left, Inamori synthetic cat's-eye alexandrite; right, natural alexandrite from Brazil. Photos by Shane McClure.

Fluorescence. When the synthetic cat's-eye alexandrites were exposed to long-wave (366 nm) ultraviolet radiation, a moderate red fluorescence was observed. This reaction to long-wave U.V. radiation is also seen in natural cat's-eye alexandrites. When the samples were exposed to short-wave (254 nm) U.V. radiation (in a dark room, with the synthetic stone lying on a black pad raised to within a few inches of the U.V. source), an unusual reaction was observed. The cabochons exhibited a weak, opaque, chalky yellow fluorescence that appears to be confined near the surface. Careful examination revealed an underlying red-orange fluorescence. This unusual reaction to short-wave U.V. radiation would not be expected in a natural cat's-eye alexandrite, and therefore provides the gemologist with an excellent indication that the piece is synthetic.

Microscopic Study. All of the samples were carefully examined with a standard gemological binocular microscope; darkfield, fiber-optic, transmitted, and polarized illumination were all used.

When the cabochons were examined with darkfield illumination, parallel striations were seen oriented perpendicular to the length of the cabochon. However, it was difficult to discern the precise nature of these striations because viewing

Figure 4. With the built-in iris diaphragm on the Gemolite microscope stage partially closed (over darkfield illumination) to create a shadowing effect in this cabochon-cut Inamori synthetic cat's-eye alexandrite, the unevenly spaced parallel growth features become more evident and reveal themselves as undulating rather than straight. Magnified 25×.

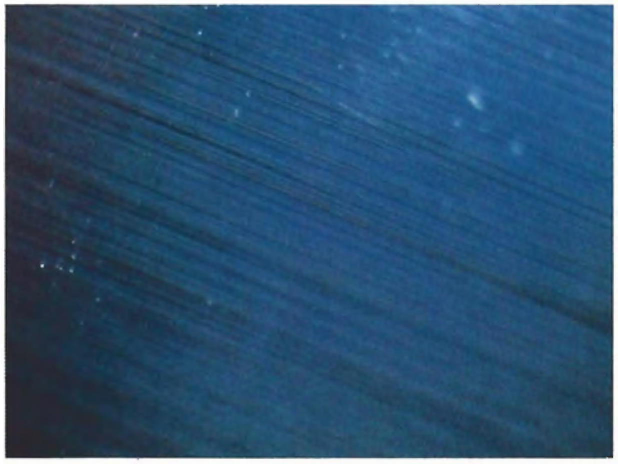

Figure 5. Oblique illumination created with a fiber-optic light unit reveals the nondescript, white-appearing, minute particles—specifically oriented in parallel planes (in association with the undulating striations shown in figure 4)—that give rise to the chatoyancy in this Inamori synthetic cat's-eye alexandrite. The larger white spots are surface features on the stone. Magnified 45×.

was obstructed by the typical "halo" seen in transparent, highly polished double cabochons. Partially closing the built-in iris diaphragm (over darkfield illumination) on the microscope stage, to create a shadowing effect, revealed that the unevenly spaced parallel growth features are undulating rather than straight (see figure 4). Such features would not be expected in natural cat's-eye alexandrites. Fiber-optic illumination revealed nondescript white-appearing minute particles that are specifically oriented in parallel planes (in association with the above-mentioned striations), and give rise to the chatoyancy (figure 5). No other distinctive features were seen with transmitted or polarized illumination. None of the inclusions resembled natural inclusions.

Natural cat's-eye chrysoberyls (non–color change, as well as alexandrite) always contain ultra-fine parallel growth tubes or needles that are oriented very close together and give rise to the cat's-eye effect when the stones are cut *en cabochon*. These inclusions are quite different in appearance from those observed in the Inamori synthetic cat's-eye alexandrites. Natural cat's-eye chrysoberyls also are frequently host to solid crystal inclusions of mica, quartz, apatite, and actinolite as well as other minerals. In addition, two- and three-phase fluid inclusions, containing both water and carbon dioxide, are commonly seen. Also typical of natural cat's-eye chrysoberyls are strong, highly visible growth features; they may be parallel, singular, straight, angular, and irregular. The Inamori synthetic cat's-eye alexandrites examined to date do not contain any of these internal features.

IDENTIFICATION AND CONCLUSION

The Inamori synthetic cat's-eye alexandrites closely resemble their natural counterparts in visual appearance, and most of their physical and optical properties overlap those of natural cat's-eye alexandrites. The key identifying characteristics of the new Inamori synthetic are: (1) the undulating growth features seen with the microscope when shadowing and darkfield illumination are used, and the white particles seen when fiber-optic illumination is used in conjunction with magnification; and (2) the unusual fluorescence seen with short-wave ultraviolet radiation.

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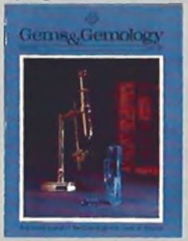

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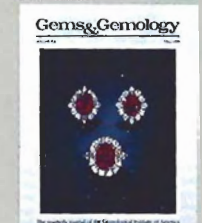

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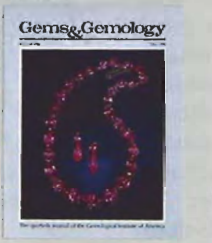

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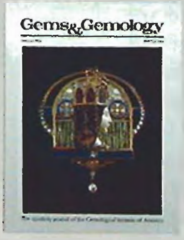

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Gem Trade LAB NOTES

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Brazilian ALEXANDRITE

All three locations of the GIA Gem Trade Laboratory have recently had the opportunity to examine a number of cut alexandrites from the new find in Minas Gerais, Brazil. The stones examined to date have ranged in size from 0.20 to 6 ct. While we do not know the extent of this deposit, there have been reports of substantial quantities of rough. The color change of most of the stones examined thus far is reminiscent of fine Russian alexandrites: from green to bluish green in day (or fluorescent) light to purple to reddish purple in incandescent light. Photos in the Gem News section of the Summer 1987 issue of *Gems & Gemology* show this change very nicely.

The properties of these stones are consistent with the published properties for alexandrite. Those the lab has seen show a very strong red transmission and a weak red ultraviolet fluorescence. Inclusions range from typical "fingerprints" and large transparent and white crystals to groups of bright stringers of tiny inclusions, very similar to those found in some flux-grown synthetic rubies. These are best seen with fiber optic illumination. Some of the stones are very clean.

The lab has also examined a few cat's-eye alexandrites from the same locality. Most exhibit the same fine color change and a well-defined, but not exceptional, chatoyancy. Apparently the silk responsible for the chatoyancy is not fine enough to create a top-quality cat's-eye effect. The largest of the cat's-eye stones we were shown was approximately one carat. *Shane McClure*

DIAMOND

Highly Radioactive Green Diamond

Green diamonds are a continuing problem for jewelers and gemologists. For many stones, it is difficult, if not impossible, to determine whether the color has been produced artificially by irradiation or is natural. However, radium-treated diamonds, though rarely seen in recent years, are readily detectable with relatively simple tests. Dark green stains are usually visible on the facet surfaces of the stone when examined with magnification. In addition, these stones are weakly to moderately radioactive and can therefore be detected by a Geiger counter. Radium-treated diamonds will also produce an autoradiograph (i.e., take their own photo from the radiation they give off) when placed in contact with a piece of photographic film for a period of time.

A 2.67-ct green marquise-shape brilliant-cut diamond that was recently examined by the New York laboratory displayed small dark green color concentrations when viewed with magnification (figure 1). The radiation detector indicated an unusually high level of radioactivity, 70 millirems per hour; the radiation rate for radium-treated diamonds we observed in the past usually ranged from 1 to 10 millirems per hour. Whereas we normally must leave a radioactive diamond on the film overnight to get an image, this stone produced an autoradiograph (see figure 2) in only an hour! One possible explanation is that this stone was only recently subjected to radium

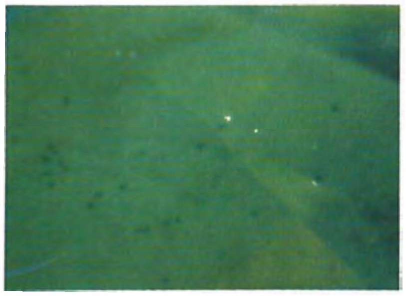

Figure 1. The dark green stains seen at 40× magnification on this 2.67-ct green diamond indicate that the stone has been radium treated.

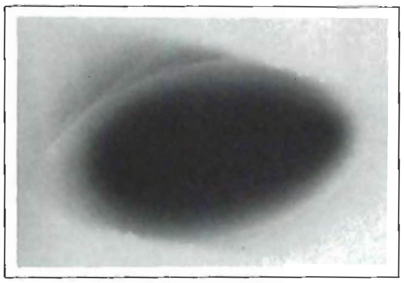

Figure 2. The radioactivity of the 2.67-ct green diamond produced this autoradiograph in only one hour.

Editor's Note: The initials at the end of each item identify the contributing editor who provided that item.

irradiation. The last stone we reported with a relatively high level of radioactivity (40 millirems per hour) was noted on page 304 of the Summer 1968 issue of *Gems & Gemology*.

Although there are no official guidelines for the use of radioactive stones in jewelry, we strongly recommend against it because of the potential health hazard to the wearer.

David Hargett

Treated Yellow Diamond with Cape Lines

A 1.09-ct yellow round brilliant–cut diamond (figure 3) was submitted to the New York laboratory for determination of the origin of the color, which at first glance appeared to be in or near the fancy intense yellow range. This stone fluoresced a weak, somewhat chalky greenish yellow to long-wave ultraviolet radiation and had a similar, but weaker, reaction to short-wave U.V. radiation. When examined with our standard spectroscope unit, the stone displayed a strong Cape series of absorption lines. However, a 498-nm and 504-nm pair, plus a vague smudge at 594 nm, were also seen. Strong Cape lines ordinarily indicate natural origin; however the suspicious fluorescence and the lines at 498 nm and 504 nm indicated a need for further testing.

Consequently, the stone was chilled with liquid nitrogen and tested with a spectrophotometer. The same absorption peaks were observed, but the 594-nm peak was now very definite. This confirmed that the stone had been treated by irradiation and subsequent annealing to improve its color.

Many treated yellow diamonds in the fancy color range that are submitted for testing show a weak Cape spectrum in addition to the lines that prove treatment; the presence of the Cape series of absorption lines indicates that the stone was originally very light to light yellow in color. However, the strength of the Cape series in this particular stone suggests that it was probably a fancy light or fancy yellow to begin with, but had been treated to make it even darker and thus fall into the more desirable intense-yellow range.

Clayton Welch

Figure 3. Although this 1.09-ct fancy intense yellow diamond showed the Cape series of lines in its absorption spectrum, further testing proved that it had been irradiated and annealed.

Figure 4. The linked ring design in which these earrings are carved is rarely seen in such fine quality natural-color jadeite jade.

Jadeite JADE Earrings

The Los Angeles laboratory recently examined the spectacular "Imperial" jadeite jade earrings shown in figure 4. Each earring consists of two translucent rings carved from a solid piece of jade so that they are linked together chain style. The largest ring measures approximately 18.6 mm in outside diameter, 7.2 mm wide, and from 2.8 to 3 mm thick. The two rings are suspended from a third carved ring-shaped piece that is fitted with a yellow metal screw-back mounting, and set with five round brilliant–cut diamonds.

The earrings were proved to be natural-color jadeite jade on the basis of their properties: a 1.66 spot refractive index, an aggregate reaction in the polariscope, and a strong 437-nm band with strong chromium lines in the absorption spectrum. The pieces were inert to ultraviolet radiation. An uneven color distribution was easily visible with magnification, as was the fine crystalline aggregate structure. However, both were much less noticeable with the unaided eye.

The most interesting feature of these earrings is the fact that such fine-quality green jadeite was used to create a linked ring design. It has been our experience in the laboratory that usually only nephrite jade or less expensive colors of jadeite are carved in a link design, presumably because so much material is lost with this type of carving. *RK*


Figure 5. The color in these cultured pearls was produced by dye.

PEARLS

Black Cultured Pearls

The New York laboratory was recently asked to identify the single strand of black cultured pearls illustrated in figure 5. There were 61 pearls on the strand, ranging in diameter from approximately 11 to 14.2 mm. At first glance, they appeared to be the expensive natural-color cultured pearls that come from the Tahiti area.

However, the X-radiograph of this same strand showed the reversal pattern that is typically seen when a silver nitrate dye has been used. Because metallic silver deposited from the silver nitrate dye solution is opaque to X-rays, it shows up as a white ring on the X-ray. Conchiolin, transparent to X-rays, normally shows up as a black ring.

Another proof of treatment is the fact that natural-color black pearls fluoresce a dull orangy red to red when exposed to long-wave ultraviolet radiation, while dyed black pearls do not fluoresce at all, as was the case here. These pearls may have been off-color South Seas pearls that were dyed to make them more salable. *David Hargett*

An Unusual Use for a Natural Pearl

The Santa Monica laboratory was asked to identify a fairly large button-shaped pearl, measuring approximately 18 mm in diameter by 13 mm deep, that was quite ingeniously used in a jewelry item. A watch is set into the pearl which is suspended from a detachable white metal swivel pendant set with small diamonds. This assemblage is in turn suspended from a white metal bow pin set with numerous diamonds of various shapes and sizes. Figures 6 and 7 show the front and back of this unique piece.

The pearl did not fluoresce to X-rays, which indicates saltwater origin. An X-radiograph taken through the side of the pearl showed structural characteristics indicative of a hollow natural pearl. However, because of the size of the watch set into the pearl we could not determine if the pearl is a natural hollow blister pearl or a natural button pearl that has been hollowed out at its base to accommodate the watch. *KH*

Scenic QUARTZ

Although we frequently encounter chalcedony (the cryptocrystalline variety of quartz) with inclusions of a scenic nature, we seldom see crystalline quartz with such picturesque inclusions. A reader from Massachusetts very kindly sent such a stone to the Santa Monica laboratory for our observation and to be shared with readers of this column.

The photo (figure 8) does not do the stone justice because the scene is actually three-dimensional. Still, it does not take much imagination to visualize dust storms swirling across a rolling desert with a mountain in the background. The jasper-like inclusion causing the scene cuts through the stone from the first row of facets above the girdle to the opposite side of the culet, following the general direction of the pavilion facets, thus giving the three-dimensional effect when the stone is viewed from the top.

The 43.36-ct gem is a slightly milky, very translucent, almost transparent variety of quartz. The refractive index is approximately 1.545, with very little discernible birefringence. The specific gravity, estimated with heavy liquids, is approximately 2.65. A bull's-eye optic figure was resolved in the polari-

Figure 6. The front view of this unusual natural pearl pendant gives little evidence of the watch that has been set into the other side of the pearl.

Figure 7. This rear view of the pendant in figure 6 shows the watch that has been set into the pearl.

scope. The stone was inert to ultraviolet radiation. *CF*

Heat-Treated Yellow SAPPHIRE

A beautiful orangy yellow oval mixed-cut stone weighing 7.60 ct (figure 9) was submitted to the Santa Monica laboratory for identification. The refractive index, birefringence, and optic figure proved that the stone is sapphire. Microscopic examination revealed natural inclusions as well as the strain discs, very fine dot-like "silk," and round cotton-like inclusions that are indicative of heat treatment.

Exposure to short-wave ultraviolet radiation revealed three zones of chalky blue fluorescence close to the girdle, another sign of heat treatment. When the stone was immersed in methylene iodide, some interesting structural characteristics became visible. In addition to the straight angular yellow color zoning alternating with near-colorless areas, which is characteristic of natural origin, three straight blue zones close to the girdle (coinciding with the areas of chalky blue fluorescence) were seen. Figure 10 shows these blue areas, which could be the result of the heat treatment. *KH*

Figure 8. Inclusions in this 43.36-ct faceted slightly milky quartz have produced an unusually picturesque three-dimensional scene.

Cat's-Eye SILLIMANITE (Fibrolite)

The mineral sillimanite was named after Benjamin Silliman, a Yale University mineralogist. It has also been called fibrolite, in allusion to the fibrous nature of the cat's-eye variety.

Sillimanite, an aluminum silicate (Al_2SiO_5), is polymorphous (the occurrence of two or more different crystal forms having the same chemical formula but with different atomic structures and therefore different properties) with kyanite and andalusite. Sillimanite itself is a rare collector's stone; cuttable gem-quality chatoyant material is extremely rare. However, cat's-eye sillimanite has been found in the gem gravels of Sri Lanka, the Mogok region of Burma, and, more recently, in Kenya.

Figure 9. This 7.60-ct yellow sapphire was found to be heat treated.

Figure 10. Blue color zones observed at the girdle of the yellow sapphire shown in figure 9 fluoresce blue to short-wave ultraviolet radiation. Magnified 3×.

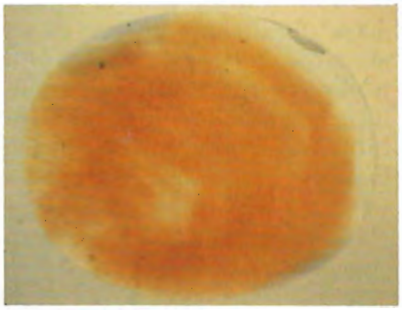

Figure 11. Cat's-eye sillimanite is very rare; this stone weighs 3.44 ct.

The Los Angeles laboratory recently had the opportunity to study the 3.44-ct cabochon shown in figure 11, a translucent to opaque very dark brown, almost black, cat's-eye sillimanite. Spot readings revealed refractive indices of 1.66 and 1.68, with a birefringence of 0.02. The stone was inert to both short- and long-wave ultraviolet radiation. Our standard spectroscope unit revealed a moderately dark general absorption up to about 490 nm, with a broad dark band superimposed at 440 to 450 nm. The specific gravity was estimated by the use of heavy liquids to be approximately 3.2.

It is interesting to note that another dealer who specializes in Sri Lankan gemstones was offering several cat's-eye sillimanites for sale at the 1987 Tucson Gem & Mineral Show, an extremely unusual display given the rarity of these stones. His pieces ranged in weight from approximately one-half to three carats and included near-colorless, violet, brownish green, and gray hues, as well as a very dark brown, almost black stone, similar in color to the stone the lab examined. *RK*

A Brownish Gray TAAFFEITE

The Los Angeles laboratory recently identified a 0.61-ct faceted taaffeite with the very unusual brownish gray color shown in figure 12. The stone was inert to both long- and short-wave ultraviolet radiation, gave refractive indices of 1.720 and 1.726, and showed a uniaxial optic figure in the polariscope. No absorption lines or bands were observed when the stone was examined with our standard spectroscope unit. Microscopic examination revealed inclusions that have previously been seen in taaffeite: a large group of very well developed pseudohexagonal prismatic crystals, a whitish "fingerprint" of negative crystals, and a few bright reflective fractures.

Although taaffeite occurs in other colors, it is usually purple to violet, with a range of saturation levels. This is the first brownish gray taaffeite we have encountered in the lab. *RK*

Figure 12. This 0.61-ct stone is the first brownish gray taaffeite ever seen at the laboratory.

A Rare Green Cat's-eye Chrome TOURMALINE

Figure 13. The rare 3.32-ct green cat's-eye chrome tourmaline shown here is reportedly from Tanzania.

Figure 13 shows a rare green cat's-eye chrome tourmaline that was recently examined by the New York laboratory. This is the first cat's-eye chrome tourmaline of this color seen by the New York lab.

Our client informed us that this material was first found in the 1960s at the Landanai mine in the Umba River area of Tanzania. Apparently only a small part of the tourmaline production is of gem quality, and most of this material is faceted; cat's-eye rough has been very rare. The needles that cause the chatoyancy in this grayish green 3.32-ct stone are eye-visible. The stone also showed a strong red reaction to the Chelsea color filter, and chromium lines in the absorption spectrum. This stone can take its place as a collector's item along with other unusual cat's-eyes such as sillimanite, kyanite, petalite, kunzite, scapolite, and zircon, some of which have been illustrated in recent issues of *Gems & Gemology* and the *Journal of Gemmology*.

David Hargett

FIGURE CREDITS

The photos used in figures 1, 5, and 13 were taken by David Hargett. Bob Crowningshield is responsible for figure 2. Figure 3 was supplied by Clayton Welch. Figure 4 is © Harold & Erica Van Pelt. Robert Weldon was the photographer for figures 6, 7, and 8. Scott Briggs furnished figure 9. John Koivula took the photomicrograph in figure 10. Figure 11 is © Tino Hammid. Shane McClure took figure 12.

Editorial Forum

THE TERM "SYNTHETIC," USE AND MISUSE

The following comments bear on issues addressed by Hanneman (Summer 1986) and Nassau (Fall 1986) in the Editorial Forum section of *Gems & Gemology* regarding use of the term *synthetic*.

With regard to functional use, in the opinion of at least eight widely recognized usage panels, convened between 1962 and 1977, the term *synthetic* may be used both as a noun and an adjective. Both cases may be traced unbrokenly to the ancient Greeks.

As to usage in meaning only, the view held by many gemologists that *synthetic* should be used only to refer to man-made materials that duplicate natural gem materials (the so-called restricted definition, as compared to the classic definition, which maintains that *any* man-made substance is a synthetic) is not shared by the overwhelming majority of the scientific community, nor by a number of competent gemologists, and certainly not by the courts. I have yet to find a ruling of the courts that found the restricted definition incumbent on the plaintiff or the defendant. The following ruling is particularly relevant:

> One synthetic may have properties closer to the natural than others; some may duplicate the natural; still others may have no natural counterpart. Whatever the degree of approach toward duplication, the substance remains synthetic. If the jewelry business wishes to differentiate between degrees of approach, that is its prerogative. However, all classes thus established would fall under, and in specification and name should not compete with, the genre known as synthetic. [*Compliance Rulings of the Courts*, 1975–1980, Vol. 32, Sect. 47, p. 201]

Nassau revives the myth that the restricted definition of *synthetic* has been used by all competent gemologists with the consistent meaning: man-made equivalent of the natural. He invokes the names of Anderson, Liddicoat, Webster, and himself as examples. In so doing, he distorts the record. After decades of adhering to this myth of consistency, Anderson conceded "the inconsistency of this double standard," here referring to the use of two definitions of synthetic by many gemologists (*Gem Testing*, 9th ed., 1980). Liddicoat, in reference to his own works, states, "That I could be accused of inconsistency in application of the term *synthetic* I admit freely. . . ." (pers. comm., 1976). After his early years, Webster flatly rejected the restricted definition in both private communications to the author and in his published works (*Gems*, 3rd ed., 1975, p. 328). Recently, Hanneman reported his similar observations (*Gems & Gemology*, Winter 1986, p. 242).

Nassau has difficulties of his own with consistency. In his book *Gems Made by Man*, he admittedly places a few materials under his espoused restricted definition that clearly do not qualify. Further, he seeks relief by stating: "The term 'synthetic' strontium titanate is thus used not in the gemological sense of being a man-made equivalent of a natural mineral, but in the technical sense of having been synthesized by man." This is indeed a strange statement. Is the discipline of gemology to be excused from conforming to technical sense? Not only does this statement add fuel to the opinion of those who feel that gemology as a discipline is not yet technically mature, but it also typifies the perplexity that advocates of the restricted definition create, to wit, *they cannot discuss synthetic stones in the necessary depth and breadth without resorting to two definitions of* synthetic, *the restricted and the classic.* In short, they use a double standard, as acknowledged by Anderson.

In analytical logic, when two or more definitions for a single term are used in a given discipline, the usage is called Delphic and is not acceptable in argument. It is a form of equivocation. The Delphic usage of *synthetic* should be abolished. Yet some gemologists still argue for continued use of this equivocation solely on the grounds that "it has long been used." Usage panels, upon first encountering the restricted definition of *synthetic*, invariably ask how such usage came to be and from where it derives enough support to survive. As for origin, this usage evolved slowly from informal exchanges between a handful of early gemologists who agreed on a needed definition but not the term for it.

After spasmodic mild debates and a draggy search for a suitable term, these individuals reached the baffling conclusion that the only solution to their problem was to take the term *synthetic* and redefine it for their purpose!

As for "enough support," it is built in. As observed by Webster (pers. comm., 1974), the advocates of the restricted definition "all drank from the same tainted font, directly or indirectly, none pausing to question the purity." To this may be added the perpetuation of mistaken ideas by teachers through indoctrinated students, strongly aided by the writings of those who were similarly inculcated before them. These authors, having long since committed themselves in print to the restricted definition, are most reluctant to admit its defects. Now, when challenged, they defend this ill-termed definition and their use and misuse of it as if it were sacrosanct.

If, after more than 30 years of refusing to believe that certain of its teachings regarding its ideal diamond brilliant might be wrong, the GIA can in 1978 correct its faulty values of girdle thickness, total depth, and resulting defects in its appraisal system, it should not be too late for responsible gemologists to accept the simpler task of eliminating the double standard for *synthetic* often found in their midst.

Eugene S. Love, D.Sc.
Boone, North Carolina

HOW TO USE "SYNTHETIC(S)"?

I agree with Dr. Hanneman (Summer 1986, Winter 1986) and Dr. Love (above) that if one looks for confusion then one will find it. Yes—there are precedents, dictionary definitions, legal usages, and so on. However, even the authorities admit that they are not consistent, as I too have not always been. Note, by the way, that Drs. Hanneman and Love do not agree with each other! Such sophistry could go on forever.

Ideally, there would be decisions made by national and international groups on such matters, so that one could get back to the important problems. Yet there is not even a consensus on the spelling of *gem(m)ology*. Let me reiterate more clearly the closing attitude of my previous letter (Fall 1986). As long as my writings are understood by the reader as saying what I intended, I am comfortable; if I have succeeded in communicating, that is all that matters to me.

Kurt Nassau, Ph.D.
Bernardsville, NJ

QUO VADIS, SPECIFIC GRAVITY? A COMMENTARY

For more than 100 years, gemological distinctions have been successfully made using specific gravity (S.G.) values of three significant figures (i.e., values carried out to the second decimal place). Today, Archimedes is probably turning over in his grave. The advent of digital scales and electronic calculators has made it easy to generate S.G. values showing three decimal places or even four, five, or six decimal places. Consequently, we are seeing more and more communications with S.G. values purporting to contain four significant figures (e.g., S.G. = 3.643).

The clear implication of such reporting is that these S.G. values have emanated from a modern "state of the art" laboratory and that they should be considered of higher quality than others that contain only three significant figures. With but few exceptions, this is nonsense.

Reporting an S.G. value of, for example, 2.778 implies that the total error associated with the two required weighings is on the order of 1 part in 10,000. For a one-carat stone, that means the sensitivity of the balance must equal at least 1/100 of a *point*. In the absence of experimental details that justify the fourth significant figure, I believe it is safe to assume *a priori* that such results are not valid. Let me explain why.

Normally, S.G. determinations are made at room temperature (20°C) and the results are reported to three significant figures (e.g., 2.78).[*] Under these conditions, no errors are introduced by ignoring the effects of temperature. In addition, the S.G. taken at 20°C is numerically equivalent to the density of the sample (also expressed to three significant figures).

Although most gemologists accept that density and S.G. are equivalent, the truth of the matter is that as the temperature rises, the density of a gem *decreases* while its measured S.G. *increases* (due to the greater change in the density of the water). If one is to consider the fourth significant figure, it is necessary to deal with these effects of temperature on the measurement. If the S.G. of the previous example were to be measured at room temperature, the result might be reported as S.G. = 2.783^{20}_{20}. The superscript represents the air temperature at which the weight measurements were made, and the subscript specifies the temperature of the water to which the mass of the object has been ratioed.

To make serious use of that fourth significant figure, it is customary to convert all ratios to water at 4°C. (Density tables of water provide the factors for conversion from any experimental temperature.) The result in this case would then be written S.G. = 2.778^{20}_{4}. The difference of 0.005 between this and the previously determined S.G. value indicates why one must report temperature data along with high-precision S.G. values.

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[*] *Specific gravity is defined as the ratio of the mass (weight) of an object to the mass of an equal volume of water at 4°C or other specific temperature.*

Investigators who have been astute enough to recognize the need for temperature notations have also recognized that the value of SG_4^{20} is, by definition, numerically equal to the density. Consequently, they simplify reporting and eliminate the need for the temperature notations by reporting values with four significant figures as *density.*

In spite of modern technology, the limiting factor in S.G. determinations is still the sample itself. The major premise on which all S.G. and density measurements are based is that the sample is homogeneous. While this is attainable for gaseous and liquid samples, it rarely is attainable with minerals. Experience shows that three significant figures is the best that we can realistically expect to get. It is not in the best interests of gemology to begin revising the tables of S.G. ranges for gems by incorporating values having four "significant" figures, or to clutter the gemological literature with impressive-looking "accuracy" that is essentially useless. For example, no really useful information is imparted by reporting that the S.G. of corundum crystals fused together with a glass flux is 3.876 or that one emerald crystal, having a few inclusions, has an S.G. of 2.689 while another, having more inclusions, has an S.G. of 2.701.

It takes a lot of good work to determine S.G. accurately to four significant figures. Such effort should be appreciated. Nevertheless, there is an axiom to the effect that if a job is not worth doing *at all,* it is not worth doing *well.* Those who violate this axiom should be judged accordingly.

W. W. Hanneman, Ph.D.
Castro Valley, CA

ERRATA

We inadvertently omitted the name of the designer of the unusual kunzite necklace that appeared on the cover of the Summer 1987 issue, courtesy of Tiffany & Co. We are pleased to notify our curious readers, who have diligently queried us, that the designer is Paloma Picasso.

On page 109 of the Gem Trade Lab Notes section in the Summer 1987 issue, the reference under the heading "Sapphirine" listed incorrect page numbers. The reference should read "Fall 1985 issue of Gems & Gemology *(pp. 176–177)."*

Continued from page 185

an offer to purchase the William Pinch collection. With the acquisition of Mr. Pinch's exhaustive collection, the museum instantly gains a place among the major museums for scope and diversity of minerals, as well as for excellent locality information. *Patricia A. S. Gray*

NY auctions thrive under new rules. R. Shor, *Jewelers' Circular-Keystone,* Vol. 158, No. 8, August 1987, pp. 448–451.

New York auction houses continue to do a booming business despite new consumer guidelines that went into effect in March of this year. Essentially, these guidelines are as follows: New York auctioneers must announce publicly if an item has *not* sold; auctioneers cannot bid up an item once it has passed its minimum reserve (the lowest bid that a seller will accept); sellers must prove clear title to anything that they put up for auction; and auction houses must inform the seller, in writing, of all charges and sales commissions. According to Stuart Rosenthal, spokesman for the New York Consumer Affairs Department, these guidelines represent "an appropriate middle ground" between auction houses and consumers.

The article goes on to expand on each of the four points, explaining the reasoning behind the guidelines. Although, in most cases, the major auction houses have adhered to these practices in the past, a move toward standardization is undoubtedly a positive step. *EBM*

Something new under the sun: 990 gold – a hard, high karat alloy. A. M. Tasker, K. Beilstein, and A. Reti, *American Jewelry Manufacturer,* Vol. 35, No. 8, August 1987, pp. 56–66.

Based on a paper that was presented at both the New York and Providence EXPOs, this article provides the technical aspects and jewelry applications of a new alloy, called 990 gold, that is very nearly pure gold.

In Hong Kong and the Far East, pure gold is preferred in jewelry for its beauty and malleability. However, it is too soft to meet the durability needs of Western jewelry manufacturers. Using the 1% impurities tolerance for pure gold in Hong Kong, Intergold has developed an alloy of 99% gold and 1% titanium that satisfies both needs.

The text covers the unique tempering characteristics of 990 gold in extensive technical detail, as well as its potential application in the jewelry trade. Three figures and one table assist in explaining the properties and usefulness of the alloy.

The alloy 990 gold is being marketed in North America and is available in wrought form only at the present time. Because of the alloy's unusual age-hardening properties, casting is not currently recommended and care should be taken when soldering this otherwise exceptional metal. In accordance with U.S. and Canadian stamping acts, jewelry manufactured from this alloy should be marked "990 Gold" or "23 3/4 karat." *EBM*

GEM NEWS

John I. Koivula, *Editor*

DIAMONDS

"Filled" diamonds. In recent months, there has been considerable discussion in the trade about the distribution of diamonds that have allegedly been filled to disguise cleavages and fractures, following a concept similar to that of oiling emeralds. Mr. Nubuo Horiuchi, of the Central Gem Laboratory in Japan, reported his observation in January 1987 of such a treatment, which diminishes the visibility of cleavages that reach the surface of some diamonds. According to Mr. Horiuchi's report, diamonds treated in this manner were discovered by the Central Gem Laboratory in lots imported from Israel. An unknown substance, possibly silicone, is being used both to give the cleavages a whitish appearance and to reduce diffuse reflections. This seems to improve the overall clarity appearance of these stones.

Since August of this year, all three locations (New York, Los Angeles, and Santa Monica) of the GIA Gem Trade Laboratory have encountered a number of imperfect diamonds that appear to have been treated by some sort of filling procedure. In September, the GIA Research Department acquired a 1.22-ct diamond (figure 1) that was reported by the dealer to have been treated in Israel to fill the fractures. Prior to its arrival at GIA, the stone had been boiled in concentrated sulfuric acid, which apparently removed some of the filling material near the surface. The result is a white, highly visible subsurface cruciform pattern across the table and crown of the stone that is probably a good representation of what the stone looked like before the filling treatment (figure 2). However, the stone also reveals a "rainbow" iridescence, not normally seen in diamonds, that appears to be the most distinctive characteristic of this treatment method (again, see figure 2).

The September 4, 1987, issue of the *Rapaport Diamond Report* states that such a treatment method was first developed by Mr. Zvi Yehuda of Israel. He purportedly introduces a "secret" ingredient into these heavily flawed stones at high pressure (50 atmospheres) and temperature (400°C). The *Rapaport Report* recommends that buyers use 20× magnification to look for small bubbles around the treated area in addition to looking for the "rainbow" iridescence mentioned above. On one of the stones that GIA has examined, a distinctive flow pattern was observed in the filled cleavages (figure 3), very different from the "feathery" appearance typical of (unfilled) diamond cleavages.


Figure 1. This 1.22-ct heavily included diamond has apparently been "filled" to minimize the cracks and cleavages. Photo by Robert Weldon.

The GIA is currently subjecting a number of suspect diamonds to a series of sophisticated tests in an effort to identify conclusively the filling material as well as to confirm the presence of such a material in a specific stone.

De Beers—Botswana—and diamonds. De Beers Consolidated Mines Limited and De Beers Botswana Mining Company ("Debswana") have reached an agreement whereby De Beers will acquire from Debswana all of the rough diamond stockpiled during the period 1982–1985 (when the diamond industry was in recession). In exchange, Debswana will receive an undisclosed cash payment, 5.27% of the enlarged share capital of De Beers, and the right to nominate two directors to the boards of both De Beers and The Diamond Trading Company (Proprietary) Limited.

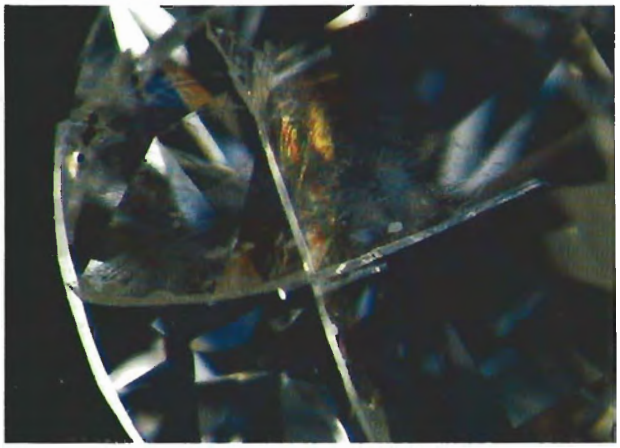

Figure 2. This white cross-like pattern on the diamond shown in figure 1 apparently was caused by removal of the filling near the surface during boiling out in an acid bath. The iridescence also seen here is characteristic of the treated portion of the cleavage system. Darkfield illumination, magnified 10×; photomicrograph by John I. Koivula.

With its three major mines—Jwaneng, Letlhakane, and Orapa—Debswana has become a major diamond producer (in terms of value) over the last decade. The combined diamond production of the Debswana mines and those already controlled by De Beers further strengthens the base of the Central Selling Organization. For its part, Debswana will obtain an investment in the diamond industry beyond its existing mines. The terms of this agreement are subject to approval by De Beers's current shareholders.

Large diamond auctioned. An unusually fine 64.83-ct pear-shaped brilliant-cut diamond was auctioned by Christie, Mason and Woods in New York on October 21, 1987. The diamond was graded D color and internally flawless, with very good polish and very good symmetry, by the GIA Gem Trade Laboratory in New York. It measures 34.10 × 22.32 × 14.79 mm. The stone does not thus far have a "name," and nothing has been released on its provenance. A photograph of this superb gem is reproduced here, in figure 4, with the kind permission of Mr. François Curiel, of Christie's, New York.

COLORED STONES

Iridescent andradite garnets. A very interesting and colorful free-form, somewhat oval, cabochon-cut gem (figure 5) was given to the GIA Research Department for examination because of its unusual appearance. The stone was originally loaned to Mrs. Lillian Meyer, departmental assistant at GIA, by Mrs. Bernice Rabb, who had purchased it in Hong Kong as a black opal. The

Figure 3. The inner surface of a filled cleavage plane in one of the diamonds examined at GIA shows the flowing rounded structures that appear to be typical of filling. Shadowed transmitted light, magnified 50×; photomicrograph by John I. Koivula.

Figure 4. This 64.83-ct D–internally flawless diamond was auctioned at Christie's, New York, in October 1987. Courtesy of Christie's, New York; photo © Tino Hammid.

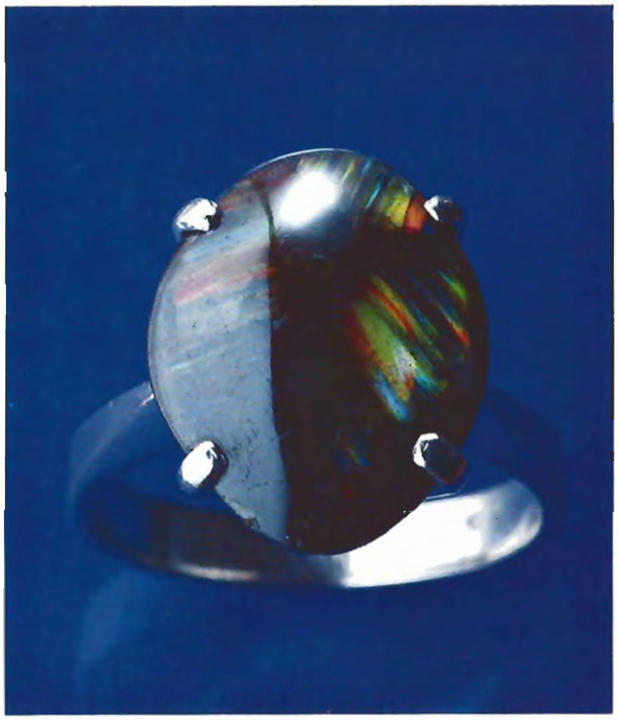

Figure 5. The stone in this ring, originally purchased as a black opal, was determined to be iridescent andradite garnet from Mexico. Courtesy of Bernice Rabb; photo © Tino Hammid.

gem measures 17.17 × 13.61 × 7.80 mm. It was not removed from the mounting for weighing, and an estimated weight could not be calculated because of the free-form shape.

The stone shows a most unusual play-of-color (figure 6) that at first glance gives it the appearance of an odd black opal. On more detailed examination, however, we found that the refractive index was over the limits of a standard gemological refractometer, and that the play-of-color seemed to be zoned or laminated in distinct planes and at angles suggesting a rhombic form for the original crystal. The material proved to be inert to ultraviolet radiation, and the hand-held spectroscope offered no additional information. On the basis of X-ray diffraction analysis, performed by C. W. Fryer, the stone was identified as andradite garnet.

At about the same time, a second, unmounted, polished free-form of the same iridescent andradite was sent to GIA Research by the New York office of the Gem Trade Laboratory for examination. This stone had been carefully cut to follow the natural rhombic dodecahedral faces of the original garnet. It weighs 44.59 ct and shows a mosaic iridescent pattern (figure 7) that is distinctly different from that shown by the mounted stone in figures 5 and 6.

Iridescent garnets have been reported in the geological literature before, but never as gems mounted in jewelry. A 1943 report (E. Ingerson and J.D. Barksdale, "Iridescent garnet from the Adelaide Mining District, Nevada," *American Mineralogist*, Vol. 28, pp. 303–312) describes such material from Nevada. Mr. Bart Curren, owner of Glyptic Illusions, Topanga, California, made a field trip to the locality described by Ingerson and Barksdale, but with little success. Although he found a quantity of iridescent garnets, the pieces were all very small and the iridescence appeared different in its structural aspects from the two stones we had examined. Thus, the Nevada locality was ruled out as the source for these much larger gems.

Subsequently, however, we met two gem and mineral dealers from Mexico who had several large polished free-form iridescent andradite garnets for sale. The color

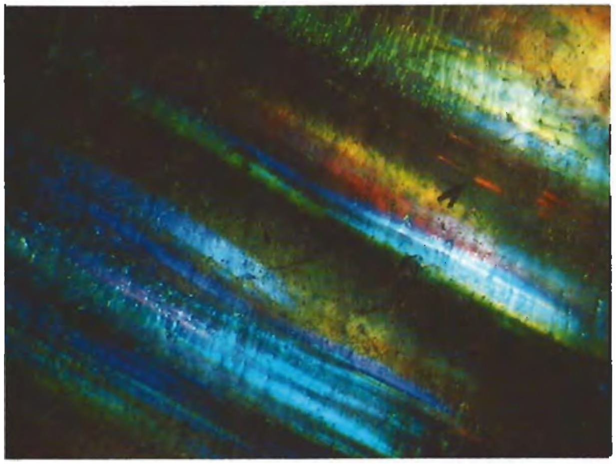

Figure 6. Bands of iridescent color are easily seen in the stone shown in figure 5. Oblique illumination, magnified 20×; photomicrograph by John I. Koivula.

Figure 7. A different, mosaic, pattern was observed in the second iridescent andradite examined. Oblique illumination, magnified 10×; photomicrograph by John I. Koivula.

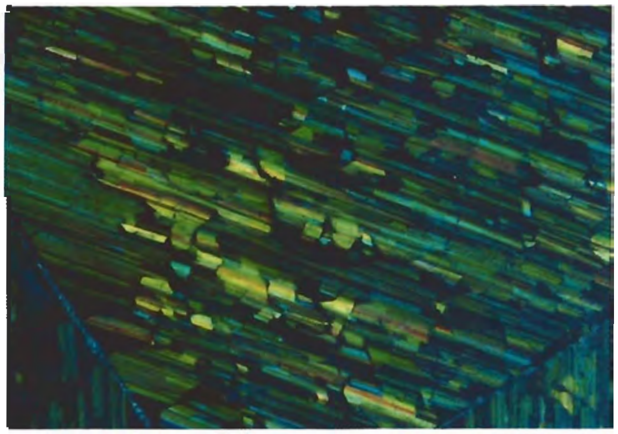

Figure 8. These two cat's-eye quartzes (the larger stone weighs 61.25 ct) are reportedly from a new locality near Belo Horizonte, Brazil. Courtesy of Hrach Chekijian; photo by Robert Weldon.

patterns of these stones were almost identical to those displayed by the two stones we had seen previously. From these dealers, we learned that the iridescent andradites are a by-product from a calcite mine located about 145 km northeast of Hermocillo, Sonora, Mexico.

Plasticized emeralds. Mr. Nubuo Horiuchi (of the Central Gem Laboratory in Japan) also reports that a number of plastic-treated emeralds have been observed over the last three years in Japan. As with oiling, the treatment only works if the fractures reach the surface of the stone. With this treatment, it appears that the fractures are first cleaned and then impregnated with an as-yet-unknown type of liquid plastic, which is then presumably hardened by exposure to light or ultraviolet radiation. This treatment appears to be much more durable than oiling, but it is nonetheless still a treatment. According to Mr. Horiuchi, it is difficult to distinguish between the plastic treatment and oiling.

Editor's note: Oiled stones have a tendency to "sweat" their oil when exposed to even slight temperature increases (e.g., during examination with a gemological microscope). A stone that had been plastic impregnated would not show this reaction. Perhaps there may also be a characteristic fluorescence. For extremely valuable suspect gems, infrared spectrometry should be definitive. The Gem News editor would greatly appreciate the opportunity to examine one or more of these plasticized stones for a more detailed discussion in an upcoming issue of *Gems & Gemology.*

Kunzite from Sri Lanka. Mr. Gordon Bleck, a miner and dealer in Sri Lankan gem materials, reports that the pink variety of spodumene, kunzite, has been found in an area east of Ratnapura at Okkampitiya. The material is described as medium to dark pink in color. There appears to be a good quantity of gem-quality material. The approximately 10-cm (4 in.) crystal examined by the Gem News editor was somewhat etched, similar to the material from San Diego County, California, and contained complex three-phase inclusions typical of pegmatitic spodumene. To our knowledge, this is the first time that kunzite has been reported from Sri Lanka.

"Rainbow moonstones" are labradorite. Dr. Henry Hänni, of the Mineralogical and Petrographic Institute of the University of Basel, Switzerland, has found through his research into feldspar mineralogy that the so-called "rainbow moonstones" coming from India are not true moonstone alkali feldspars, but rather are labradorite feldspars. Microprobe analysis provided the identification.

These labradorite feldspars get their phenomenal color effects by diffraction from lamellar growth, in the same way that the Finnish spectrolite-labradorites do, and not from exsolution of albite in orthoclase – as is the case with true adularescent moonstones. However, because they lack the ilmenite inclusions that give most labradorites a dark grayish background body color, these feldspars appear white to almost colorless, and thus the misidentification.

Phenomenal quartz from Brazil. Mr. John Bradshaw, curator of the Harvard Museum's gemstone collection, sent Gem News a selection of translucent to semitransparent orangy brown cat's-eye quartzes that have been coming out of a locality near Belo Horizonte, Minas Gerais, Brazil. The gem-quality stones examined thus far range in weight from 24.58 to 61.25 ct; they are the property of Mr. Hrach Chekijian. Some of the stones show weak stars with one very strong ray producing the chatoyancy, while others show only one strong chatoyant ray. One of each type of stone is shown in figure 8. We do not know how much of this material is available, but the stones appear to have excellent jewelry potential.

Included quartz from Mexico. Rock crystal quartz containing inclusions of marcasite, with minor amounts of pyrite, chalcopyrite, silver, and gold, is being produced at the Solaverna mine in Zacatecas, Mexico. The material is so densely filled with marcasite and the other inclusions that it appears almost black and, for all practical purposes, is opaque. The material is being cut into beads and sold under the trade name Solavernite.

New ruby locality in Afghanistan. Mr. Gary Bowersox, president of Gem Industries, Inc., in Honolulu, Hawaii, reports that a new find of gem-quality ruby has been discovered in Afghanistan, northeast of Kabul. This mine is unrelated to the deposit near Sorobi, known as the Jegdalek mine, that was reported by Mr. Bowersox in his article "A Status Report on Gemstones from Afghanistan," which appeared in the Winter 1985 issue of *Gems & Gemology*.

Heat-treated pink sapphires. Mr. Gordon Bleck also has informed us that many Sri Lankan pink sapphires are heat treated in Sri Lanka to improve their color by driving off any blue overtones that may be present. The heating is done in air in an open fire. The temperature reached during this type of heat treatment may be as high as 1100°C.

New locality for topaz. In the July 1987 issue of *Mineral News*, Lanny R. Ream reported on a major new find of topaz in the northeastern United States. The deposit is said to be in the state of New Hampshire, but more accurate locality information was not available. The specimens from this new source are reputed to be of top quality.

Treated cat's-eye zircons. Although chatoyant zircons are not particularly common, they have been reported in the literature from time to time. They are known to occur in a variety of colors, such as green, brown, and pale yellow. Mr. Gordon Bleck informs us that some of these "cat's-eye" zircons have in fact been treated to create a false eye. To fabricate chatoyancy in zircon, Mr. Bleck reports, "feldspar is melted onto the back of the zircon" cabochon. However, "the backs of the cabochons must be left somewhat rough in order for the treatment to work." Mr. Bleck uses a simple test to detect these false cat's-eyes. He rubs an emery board across the back of the cabochon in question; if the stone has been treated, the cat's-eye will disappear. With a microscope, it is also possible sometimes to see small natural pits and scratches that have been filled in by the melt.

Acknowledgments: In addition to those individuals mentioned specifically in the Gem News text, the editor would like to thank Dr. Emmanuel Fritsch, Mr. C. W. Fryer, Ms. Patricia Gray, Mr. Robert E. Kane, Dr. James E. Shigley, and Ms. Carol M. Stockton for supplying useful information for this column.

ANNOUNCEMENTS

The Tucson Gem and Mineral Show will be held February 11–14, 1988, at the Tucson Community Center. The featured species for the show is beryl. For more information, contact the Tucson Gem and Mineral Society, P.O. Box 42543, Tucson, AZ 85733.

The American Gem Trade Association (AGTA) will again be in Tucson, February 6–11, at the Doubletree Hotel. Along with their usual seminars and trade shows, AGTA will announce the winners of the Spectrum Award (a jewelry contest aimed at the effective use of colored stones) during that time. The deadline for entries for the Spectrum Award is November 4, 1987; for information, contact the AGTA headquarters at the World Trade Center #181, P.O. Box 581043, Dallas, TX 75258, (214) 742-4367. AGTA is also offering special travel rates; call (800) 972-1163. The GLDA show will be at the Holiday Inn Broadway, February 6–14; for information call (602) 742-5455.

The Gemological Institute of America will have various lectures and seminars at the Holiday Inn Broadway, February 6–11. For information, call (800) 421-7250, ext. 227, or write GIA, 1660 Stewart St., Santa Monica, CA 90404. The American Gem Society (AGS) will also present seminars and other activities at the Viscount Suite Hotel, February 3–8. Contact AGS at 5901 West Third St., Los Angeles, CA 90036, (213) 936-4367.

Numerous other shows will be held at various locations around Tucson (e.g., the Holiday Inn/Holidome, the Sheraton Pueblo Inn, the Tucson Pima County Fairgrounds, the Desert Inn, and the Americana Hotel) during the same period.

The Asian Institute of Gemological Sciences, Bangkok, Thailand, announces the publication of its quarterly newsletter *Gemological Digest*. Written in English, *Gemological Digest* will feature articles on a variety of subjects, including gemology, jewelry, and important issues that affect the trade. The first issue, available now, contains articles on the disclosure of treatments and the pink sapphire vs. ruby controversy. *Gemological Digest* is free to all members of the trade. For more information, contact the Asian Institute of Gemological Sciences, 987 Silom Road, Rama Jewelry Building, 4th Floor, Bangkok 10500, Thailand.

BOOK REVIEWS

Elise B. Misiorowski, Editor

HARRY WINSTON, THE ULTIMATE JEWELER, 2nd edition

*By Laurence Krashes, 218 pp., illus., publ. by Harry Winston, Inc. (New York) and the Gemological Institute of America (Santa Monica, CA), 1986. US$75.00**

Dedicated to the memory of Harry Winston, this book is a lavish tribute to his skill and imagination. Vivid and alluring, it is a spectacle of treasures and certainly a complement to any library.

The book is well organized into three main sections. The first unfolds the fascinating life of Harry Winston, tracing the chronology of his most notable achievements in the jewelry trade. The second section presents descriptions, and in most cases illustrations, of 48 historically important diamonds handled by Winston at one time or another. Although the introduction states that "the original intention of this book was to reproduce those entries [relating to Winston stones] in the Gemological Institute of America's *Diamond Dictionary*," this second section alone surpasses that intention by providing an updated, readable guide that rivals any reference now available on the subject. The third section is devoted to the genius of Winston's jewelry designs. A succession of full-color photographs and drawings illustrate Winston's commitment "to place emphasis on the beauty of the gemstones themselves." Of these photos, fewer than 10% have ever appeared in print before.

The author should be commended for his engaging style and skillfulness in adding a sense of drama and excitement to the intriguing anecdotes. The depth of information provided, especially regarding the provenances and subsequent histories of Winston's major transactions, indicates that much thorough research was involved. To its benefit, this second edition has been slightly re-arranged and expanded from the original version. Having the contents page closer to the beginning allows the reader to reference more quickly, and additional footnotes bring more depth and clarity to the text; approximately 20 of the color pieces are new to this edition. Over 130 color and 30 black-and-white illustrations are included.

It is difficult to find any significant flaws in this book. Although there are problems with the reproduction of a few of the color illustrations, this is probably due to the quality of the original photographs, since several of the pieces date back to the 1950s and early 1960s. Otherwise, it appears that no detail has been overlooked in the production. Priced at $75.00, the book is undeniably a worthwhile investment.

CAROL P. ELKINS, G.G.
Sotheby's, Beverly Hills, CA

ALEXANDRE REZA: DREAMS OF YESTERDAY, REALITIES OF TODAY.

*by Arlette Seta, 120 pp., illus., publ. by Editions d'Art Monelle Hayot, Paris, 1985; trans. by Christine Jones. US$50.00**

Written as a showcase for the work of master jeweler Alexandre Reza, this book also provides an overview of jewelry design throughout history. Reza's jewels demonstrate once again what modern designers often forget: that there is a timelessness about jewelry. Historically, designs in jewelry are rediscovered and imitated in successive centuries. Modifications are made with advances in technology, but the initial beauty of a classic jewel remains unchanged with the passage of time. Reza's jewels are all replicas or adaptations of jewelry designs found in archaeological sites, Renaissance paintings, and jewelry design books from the 17th through 19th centuries.

Incorporating modern methods of gem cutting to maximize the color and brilliance of the gemstones, and using current technology in precious metalsmithing, Alexandre Reza's workshops in Paris produce sumptuous suites of jewelry that are both current and fresh and yet echo back to earlier centuries.

The text describes the evolution of jewelry design throughout history, focusing on those styles that Reza has replicated. Peppered with quotes and anecdotes of the royalty who commissioned these jewels and the masters who designed and fabricated them, the book provides much interesting information about the symbiosis of art and power. Although emphasis is naturally placed on French jewelry design, German, Austrian, Italian, Russian, English, Persian, and Indian designs are also represented.

Unfortunately, the original overly florid French text has been inexpertly translated and the result is difficult to read and at times unintentionally humorous. A too-literal translation has given rise to stilted expressions that obscure rather than clarify the meaning of the text, along with a few words that are totally new to the English language.

The book was apparently compiled to document an exhibition at the Jacquemart-André Museum, but further details about the exhibit are not given. A foreword by Reza himself and an introduction by René Huygue, director of the Jacquemart-André Museum, give a glimpse into the character of the otherwise enigmatic artist who has produced these luscious jewels. A scholarly bibliography and 80 exquisite illustrations, 48 in color, are themselves sufficient reason to acquire this book.

ELISE B. MISIOROWSKI, G.G.
Research Librarian, G.I.A.

**This book is available for purchase at the GIA Bookstore, 1660 Stewart Street, Santa Monica, CA 90404.*

CRYSTAL GROWTH PROCESSES

*By J. C. Brice, 298 pp., illus., publ. by Blackie/Halstead Press, Glasgow, 1986. US$61.95**

John Brice is a veteran of over 25 years in the field of crystal growth in the United Kingdom laboratories of the giant Philips Company. A major contributor in the field, he has been particularly concerned with electronic materials, including materials for optical devices. He has authored two previous books, *Crystal Growth from the Melt* and *Crystal Growth from Liquids*, which cover more specialized aspects of the subject and have been quite popular within the crystal-growth community. This third book, *Crystal Growth Processes*, is directed at scientists and engineers who are required to grow crystals, but it is basic enough to serve as an introduction to the whole field of crystal growth for students and others who have an interest in this subject.

Brice's main expertise is in the often gray area between the theory and the practice of crystal growth. The book contains a set of theoretical models that attempt to specify parameters such as the crystal growth rate as a function of the system variables. The systems now used to grow crystals commercially are often extremely complex, and are difficult to describe by relatively simple equations. However, Brice does a good job of setting out equations that can guide the researcher or engineer to make quantitative predictions about the effects of changing the system variables. The underlying principles are also well described.

The book has three main sections. The first, comprising roughly one-third of the text, discusses the uses of single crystals and methods of growth. The author estimates that 900 tons of crystals are grown each year for the jewelry industry. The major part of this section discusses basic concepts—chemical bonding, defects in crystals, phase diagrams, the crystal surface, growth kinetics, transport processes, and an approach to a generalized (mathematical) description of crystal growth. The next section, which makes up more than half the book, is devoted to each of the major methods of crystal growth—liquid, vapor, and solid sources—with emphasis on electronic materials. However, only two pages are devoted to Verneuil's flame-fusion process, the most popular for the economic growth of some gem materials such as sapphire. The comment that "Verneuil-grown crystals tend to be rather imperfect and suitable for uses where imperfections do not matter (e.g., jewellery) . . ." illustrates the author's perspective. The skull-melting method, which is used to make cubic zirconia crystals, receives a one-page description.

The final chapter is concerned with the selection and optimization of methods of crystal growth, and includes a short review of the techniques of crystal characterization. This useful section, which is not usually found in a book of this kind, discusses the economics of crystal production.

In summary, *Crystal Growth Processes* is a book for the serious practitioner of the subject, especially one who is comfortable with applying equations to compare theory with practice. It is probably the best introduction to the subject of crystal growth for an engineer or advanced student, and will be of value to the experienced crystal grower who has been used to a "seat-of-the-pants" approach and wants to try something more quantitative. Even someone who does not want to get involved with the equations will benefit from the discussion of fundamentals. For the most part, however, the gemologist who wants to know more about the ways in which synthetic *gem* crystals are produced will find more on this specialized topic in *Gems Made by Man* by Kurt Nassau, or in this reviewer's (unfortunately more expensive) *Man-made Gemstones.*

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GEMOLOGICAL ABSTRACTS

Dona M. Dirlam, Editor

COLORED STONES AND ORGANIC MATERIALS

Beryl: Beautiful "accidents" of nature. R. C. Kammerling, *Jewelers Quarterly,* First Quarter, 1987, pp. 6–8, 10–11.

The author has produced an informative yet easy-to-read article on three gem varieties of the mineral species beryl: aquamarine, morganite, and golden beryl (heliodor). For each variety, mining regions, causes of color, color enhancement, famous stones, history and lore, and the evaluation of color are discussed. Aquamarine, the best known of the group, is described in much more detail than the others. Kammerling concludes by emphasizing that it is the inclusion of impurity elements that produces the different color varieties of beryl.

Barton C. Curren

Les gemmes en lumière: Quand les grenats jouent aux opales. (Gems in light: When garnets act like opals.) C. and A. da Cunha, *Monde & Minéraux,* No. 79, May–June 1987, pp. 30 and 35.

The authors describe in some detail a parcel of iridescent garnets recently collected in the American Southwest. Iridescent lamellae exhibiting all the colors of the rainbow are oriented in three directions on a reddish black background. Microprobe analyses of a rough crystal and a cabochon showed that this material is a mixture of andradite, almandite, and grossular. The origin of the iridescence is discussed, with reference made to a series of Japanese studies dealing with iridescent garnets of somewhat similar composition from Adelaide, Nevada, and Kamihogi, Japan. Two types of lamellae are found in both cases: one rich in iron, the other rich in aluminum. The iridescence depends on the spacing and thickness of the lamellae. Three color photographs illustrate this article. *EF*

This section is designed to provide as complete a record as practical of the recent literature on gems and gemology. Articles are selected for abstracting solely at the discretion of the section editor and her reviewers, and space limitations may require that we include only those articles that we feel will be of greatest interest to our readership.

Inquiries for reprints of articles abstracted must be addressed to the author or publisher of the original material.

The reviewer of each article is identified by his or her initials at the end of each abstract. Guest reviewers are identified by their full names. Opinions expressed in an abstract belong to the abstracter and in no way reflect the position of Gems & Gemology *or GIA.*

Jade, stone of heaven. F. Ward, *National Geographic,* Vol. 172, No. 3, September 1987, pp. 282–315.

In this comprehensive article, Ward traces the history of jade—both nephrite and jadeite—through a first-hand account of his travels to the world's major jade-mining and carving localities. His narrative takes the reader from the Kunlun Mountains of Xinjiang Province, in the People's Republic of China, where alluvial boulders of white nephrite are found, to Rangoon, Burma, with its annual jade auction and gem emporium. He also describes nephrite mining in such localities as British Columbia, South Australia, and the Arahura River of New Zealand, as well as jadeite recovery in Guatemala, once a source of Mayan jade. Throughout the article, the author discusses the historical, aesthetic, etymological, and commercial aspects of jade, including accounts of jade carving in Hong Kong, dealings in smuggled jadeite in northwestern Thailand, and the use of the Chinese word for jade, *yu,* to describe a number of other materials suitable for carving.

Of particular interest to gemologists is a section dealing with the problems of identifying the jades—and their separation from a number of other materials called "jade" by both past and present cultures. In this respect it is unfortunate that, as the author points out, archaeologists "are confusing an already muddled history by introducing a new term to encompass all carved green material—'cultural jade.'" This section includes a discussion of a portable instantaneous display and analysis spectrometer (PIDAS) that can be used to identify artifacts thought to be jade.

This article is very well illustrated, as we have come to expect in all reports published in *National Geographic.* It is "must" reading for today's jeweler-gemologist. *RCK*

Une nouvelle variété noble de feldspath (A new gem variety of feldspar). E. Gübelin, C. R. Bridges, and G. Graziani, *Monde & Minéraux,* No. 79, May–June 1987, pp. 20–24.

Light blue to light green gemmy feldspars were recently discovered near Kioo, Kenya, 13 km east of Sultan Hamud. They are found in pegmatite dikes that intrude metamorphosed Precambrian sediments. The pegmatites also contain large gem blue kyanites, garnets, quartz, black tourmalines, and vermiculite (a mica). The deposit is mined with explosives and hand tools. The feldspar is very similar in color to aquamarine; the luster is vitreous. The refractive indices are $n_\alpha = 1.531$, $n_\beta = 1.535$ and $n_\gamma = 1.539$, with $2V = 90°$. Optical measurements, together with X-ray diffraction and electron microprobe results, indicate an oligoclase (6.2% anorthite) with a peristerite structure. The inclusions observed are unique growth inhomogeneities (a picture is provided), "fingerprints" with occasional two-phase inclusions, and vermiculite crystals. Three color photographs and eight other figures illustrate this article. *EF*

The joy of jade. D. Kaye, *Town & Country,* Vol. 41, No. 5085, June 1987, pp. 126–129, 171.

Written for the general reader, this article covers some of the history and lore of jade and attempts to explain some of the unexpectedly high prices recently paid at auction for jade items.

While there is some useful and interesting information here, the article is wanting in a number of areas. When discussing the high prices paid for various pieces, the author does not state whether the item in question is jadeite or nephrite; thus, the price paid for a necklace consisting of what is probably fine-quality jadeite is equated with that paid for nephrite carvings of great historical value. In fact, most of this discussion takes place before the author ever mentions that jade is really two distinct minerals. This failure to distinguish between jadeite and nephrite also carries over to the photographs, where only 3 out of 15 are identified as to type of jade. *RCK*

DIAMONDS

Cleavage surfaces of diamond. E. M. Wilks and J. Wilks, *Industrial Diamond Review,* Vol. 47, No. 518, January 1987, pp. 17–20.

The smoothness and reproducibility of cleavage patterns in gem-quality diamonds were investigated for three groups: type I brown diamonds, which tend to cleave with a rough surface; type II diamonds, which have relatively smooth and uniform cleavages; and type I colorless diamonds with a high degree of lattice perfection, which cleave more smoothly than the type I browns but less so than the type II diamonds.

While stones within each group showed marked similarity in cleavage patterns, the differences between groups were significant. This variability is attributed to large-scale variations in crystal structure that arise from the presence of impurity atoms, as revealed by X-ray topography and cathodoluminescence studies. The higher concentrations of impurities in type I, especially brown, diamonds contribute to the rougher cleavage surface typically observed. *EF*

Diamond dilemma—how discounting is reshaping the market. R. Shor, *Jewelers' Circular-Keystone,* Vol. 158, No. 6, June 1987, pp. 134–147.

The obsession with cost control is changing traditional patterns in the world diamond market. The slow cash flow and thin margins available to sightholders have prompted them to bargain with De Beers as never before. At the same time, De Beers, under the new leadership of Nicholas Oppenheimer, appears to be listening to the sightholders and seems to be heeding some legitimate complaints. Yet, although De Beers is watching its costs to producers, it is also facing stiff resistance to its second price increase in less than a year. With an eye on world politics, the Central Selling Organization recently moved its headquarters to Lausanne, Switzerland. However, CSO spokesman Richard Dickson, emphasizing that most activity is still conducted in the London office, stated that the move "has no effect on our day-to-day operations."

With the price and supply of diamonds controlled by De Beers, the biggest cost saving available to cutters is to move production to countries where labor costs are extremely low. Third-world countries such as China, Malaysia, and Thailand, as well as Hong Kong, are putting pressure on traditional cutting centers such as Antwerp, New York, Israel, and even India.

In Belgium, the devaluation of the dollar by 33%, coupled with the government's crackdown on under-the-counter payment to workers, has virtually doubled cutting costs. Automated cutting helps some plants cut expenses, but Antwerp is no longer competitive for stones under a quarter carat.

In New York, business is strong, but price resistance keeps margins small. The outlook here is for continued specialized cutting of only the biggest and best because of the competition from Antwerp and Israel in finished sizes under 2 ct.

The Israeli industry has dramatically broadened its share of the U.S. market with mass merchandisers, manufacturers, and chains. New "grain-finding" Piermatic polishing machines have helped Israel remain price competitive in the face of increased competition from India.

India, fearing competition from Asian countries that pay even lower wages, now allows importation of high-tech polishing equipment. Worldwide, conservative bank lending continues to dampen speculation in the market. At the same time, the Japanese buying spree appears to be losing momentum.

Retailers, faced with cut-throat price competition, are increasingly turning to Asian jewelry manufacturers. Big firms such as Sears and Best Products have both established buying offices in Israel, thus curtailing the business of traditional New York importers. It is obvious that cost cutting is changing the face of the world diamond business. *James R. Lucey*

Diamonds: Giant leap in 1986 production. J. Roux, *Jewellery News Asia,* No. 36, August 1987, pp. 45–50.

In 1986, world diamond production soared to a record height of more than 88 million carats. This leap was primarily the result of Australia's 1986 diamond production figures, which swelled to over 29 million carats from the 1985 figure of approximately 7 million carats. This surge elevated Australia to the world's largest diamond producer. Production in other countries changed little, except for Botswana and Zaire, both of which showed substantial increases.

In Botswana, diamond production increased to 13,090,407 carats, up more than 450,000 carats from 1985. In Zaire, production increased by around 1 million carats in 1986, the result, in part, of new governmental policies and regulations designed to restructure independent and foreign mining interests and reduce smuggling. South African production rose only minimally. The decrease in ore grades from several mines, together with the retrieval of lower-grade material from dump recovery efforts, offset increases at the Premier and Namaqualand mines in South Africa.

Namibia boosted production nearly 100,000 carats to a 1986 total of over 1 million carats. In Tanzania, production dropped by more than 100,000 carats due to low ore grade at the Williamson mine and a shortage of development capital. In Angola, production decreased dramatically, from approximately 700,000 carats in 1985 down to 200,000 carats in 1986. Civil war and the transition of Diamang from government owned to privately run are cited as the major causes for the decline.

Extensive exploration efforts are particularly active in Australia, Indonesia, China, and Sierra Leone. De Beers is continuing worldwide exploration in Africa and the Americas as well.

As usual, accurate production figures are not available for most diamond sources. The data used for this article were compiled mainly from U.S. Bureau of Mines reports and the British publication *The Mining Journal.* It should also be noted that the article discusses total rough diamond production without reference to gem vs. industrial quality, sizes, or detailed grade/tonnage information. Regardless, the article is helpful as a general and comparative overview of 1986 diamond production worldwide. *Gail L. Kirchner*

INSTRUMENTS AND TECHNIQUES

Confusing colourless stones. D. Kent, *Journal of Gemmology,* Vol. 20, No. 6, 1987, pp. 344–345.

This short article is primarily a discussion of why and how the author has assembled a collection of colorless natural gemstones and diamond simulants. The value of the article lies in a chart Mr. Kent has included that shows infrared reflectometer readings and refractive indices for each of the 39 faceted gem materials in his collection, along with carat weight and specific gravity. It is interesting to see the correspondence between the infrared reflectometer readings and R.I. *EBM*

JEWELRY ARTS

B is for beautiful. C. Seebohm, *Connoisseur,* Vol. 217, No. 902, March 1987, pp. 59–65.

Daughter of jewelry giant Constantine Bulgari, Marina Bulgari was raised with an understanding of, and appreciation for, fine jewelry. From the age of 12, Marina was involved in her family's business; steadily, she developed her talent as a designer. In the 1970s, when the third generation of Bulgaris inherited control of the company, Marina found that "there were too many of us with too many differing philosophies." Needing the freedom to express herself, Marina broke away from the company; in doing so, she agreed to the stipulation that she not use the Bulgari name. In 1979, Marina opened her first jewelry showroom in Geneva as simply Marina B.

Marina Bulgari's opulent and extraordinary designs are intricately fabricated, with interchangeable parts, swivels, hidden springs, and invisible clasps, so that the jewels are as comfortable to wear as a piece of clothing. She makes good use of a variety of gems and precious metals, mixing them with a "disdain for intrinsic value." Topaz, citrine, amethyst, and tourmaline are accented with diamonds, black enamel, or black mother-of-pearl, and set in gold or platinum. Her designs also make use of cabochon stones because, as she claims, they "create volume." Marina's often custom-designed, one-of-a-kind jewels command extravagant prices that maintain her exclusivity.

The author has performed a service by providing this glimpse into the private Bulgari world, and focusing deserved attention on a dedicated and innovative artist. The text is accompanied by eight rich photographs of Marina B. jewels. *EBM*

How to copyright your designs. P. L. Berger, *American Jewelry Manufacturer*, Vol. 35, No. 6, June 1987, pp. 24, 26, 28.

Jewelry manufacturers may effectively protect their designs by registering them with the U.S. copyright office. This article outlines the procedures a jewelry manufacturer or designer must follow to register original designs with that office.

Applying for a copyright is actually very easy. Unlike patents, a copyright can be obtained without the aid of a lawyer. It requires a simple three-step process: (1) fill out Form VA, including drawings or photographs of the design; (2) attach a check to cover the $10.00 fee; and (3) mail the information to the Register of Copyrights, Library of Congress, Washington, DC 20559. A manufacturer may register several designs at one time provided the proper guidelines are followed. The author also gives several pertinent examples of how designers and manufacturers can protect themselves with a copyright. *Juli L. Cook*

Celtic gold torcs. C. Eluère, *Gold Bulletin*, Vol. 20, No. 1/2, 1987, pp. 22–37.

This article is a detailed study of gold torques, or neckrings, worn by the barbarian Celtic tribes in Europe and the British Isles from roughly the 5th to 1st centuries B.C. Using modern technology, the author analyzed the gold alloys used, and postulates on the tools that would have been employed to fabricate these deceptively simple ornaments.

Ms. Eluère begins by discussing classic historical references to torques in literature and sculpture. She then examines torques classified in groups according to their different terminals and clasps. These categories were selected because they reflect advances in technology.

It is hard to characterize as "barbarian" a culture that devised such sophisticated fasteners and intricate and graceful designs. Strong and bold, but accented with details, these pieces are worthy of close examination by jewelry designers today.

Tribute must be paid to the exhaustive research that went into the writing of this paper. Although it seems a bit clogged with dates and locations (a map would have been helpful), the information is worth digging for. Over 25 photographs, many in color, embellish the text, and 48 references are cited. *EBM*

JEWELRY RETAILING

Perlstein victims unpaid; judge rewrites restitution. W. Keane, *National Jeweler*, August 16, 1987, p. 12.

Keane updates the case involving Ron Perlstein, Philadelphia's "discount diamond king," who was ordered by the court to pay restitution to 613 of his customers. As of July 1987, only 33 customers had received any of the payment ordered by the court in 1986. In an effort to speed up the repayment, a municipal court judge in Philadelphia imposed a new restitution order on July 13, 1987. However, Perlstein is saving $200,000 as the result of the court's restitution rewrite. Some victims are furious with the court; others are willing to take the lesser amount. Customers have the option of taking the diamonds as advertised, a cash amount, or store credit. *GAR*

The Tiffany standard. C. Hemphill, *Town & Country*, Vol. 141, No. 5080, January 1987, pp. 158–164.

To commemorate the 150th anniversary of Tiffany & Co., the author presents a fascinating historical sketch that focuses on the people who contributed most to Tiffany's superior international reputation. Through brief vignettes, we follow the growth of the company from novelty shop and dry-goods store to an exclusive jewelry establishment that has catered to the elite since the turn of the century.

Although Charles L. Tiffany, the founder, had an understanding of the American public's taste during the 19th century (a bit vulgar and sensational), he nonetheless had a "seriousness of purpose and a ruthless standard of quality." Among the designers who made Tiffany & Co. great: silversmith Edward C. Moore, who reflected the classical and Rococo revivals of the 1850s and 1860s; Louis Comfort Tiffany, known for his magical opalescent glass and unusual Art Nouveau jewelry in the early 1900s; Van Day Truex, whose bold colors and provocative designs during the 1950s brought life back to the "ghastly good taste" that typified Tiffany's during the war years; Jean Schlumberger, the Parisian designer who joined Tiffany's in 1956 and continues to produce highly stylized jewelry in a colorful mixture of mythical and natural subjects that is his translation of Renaissance mannerism; Elsa Peretti, a Roman aristocrat whose stylized organic designs in silver became wildly popular in the 1970s; and Paloma Picasso, who in the 1980s is proving herself with strong, simple jewels incorporating large colored gems. Although not a jewelry designer, Gene Moore, the celebrated window dresser for Tiffany's, is also given deserved attention. The several presidents of Tiffany's are mentioned as well, but they must take a place in the background to the creative individuals who set the Tiffany standard. Photographs of several of the designers are included, together with an example of each one's work. *EBM*

SYNTHETICS AND SIMULANTS

Czochralski growth of alexandrite crystals and investigation of their defects. X. Guo, M. Chen, N. Li, Q. Qin, M. Huang, J. Fei, S. Wen, Z. Li, and Y. Qin, *Journal of Crystal Growth*, Vol. 83, 1987, pp. 311–318.

Optical-quality crystals of synthetic alexandrite have been grown by the Czochralski method. These crystals are up to 90 mm in length (along the c-axis) and 18 mm in diameter. Oxide starting materials mixed in stoichiometric proportions are used to produce (by solid-state reaction at 1300°C for 12 hours) a sintered block of polycrystalline alexandrite. This block is then melted in an iridium crucible and the crystal is grown by the Czochralski method at 1870°C. Crystals have been grown oriented along the [100], [010], and [001] directions. The crystals exhibit a distinct anisotropy of growth rates along these three directions such that [100]>[010]>[001]. Various structural features observed with an optical microscope in these crystals include bubbles, inclusions, dislocations, and grain boundaries. These features were examined in greater detail using both transmission and high-resolution electron microscopy, and were found to be related to defects generated during crystal growth. *JES*

Esmeraldas sintéticas, sustitutos e imitaciones de esmeralda (Synthetic, substitute, and imitation emeralds). M. A. Pellicer, F. Gascon, and M. Baquero, *Cuadernos de Gemologia*, No. 4–5, January–December 1986, pp. 147–157.

This article, written in Spanish, describes the history and major developments of synthetic emerald production. The authors begin with the first efforts of Mr. Ebelman of France, in 1848, and continue through the present production and development; basically, the article is a succinctly presented chronology. The producers covered are: Verneuil, Hautefeuille and Perrey, Chatham, Gilson, Zerfass, Lennix, Inamori, Seiko, Lechleitner, Linde, Regency, and Biron. A final paragraph is dedicated to a short description of beryl substitutes.

Hand-rendered sketches depict the most typical inclusions in the various synthesized emeralds. Although the examples are realistic enough to impart a feeling that one could recognize the inclusions in real stones, one cannot help but wonder why photomicrographs were not used.

For the gemologist fluent in Spanish who has long wondered about the translations of some of the more technical gemological terms, this is an excellent opportunity to exercise and understand the terminology in another language. The article is well researched, the information cleverly compounded, and the bibliography gives the reader recourse to further information.

Robert Weldon

The first plastic. R. Friedel, *Invention and Technology*, Summer 1987, pp. 18–23.

The first plastic emerged from man's desire to produce a material that could replace ivory in billiard balls. John Wesley Hyatt, a New York printer, invented the first plastic, a celluloid, in 1869. Experiments in the 1880s and 1890s resulted in a celluloid material that could be easily shaped and dyed to look like ivory, tortoise shell, and mother-of-pearl. Although this celluloid failed as a billiard ball, its most important attribute was its ability to imitate items of rarity and value at a much lower cost.

The celluloid material appealed to the tastes of the turn-of-the-century middle classes. The substance lent itself to a great range and variety of ornamental uses. As a result, it was mass-produced into letter openers, jewelry boxes, combs, and sewing kits. In addition to its decorative uses, celluloid became a very important component of early photographic film.

The commercial importance of celluloid continued through the 1930s, although rival products had begun to emerge. The flammability of celluloid was incentive to produce substitutes in the growing film industry and elsewhere. At present, little celluloid is produced in the United States. There are very few applications for the substance, and its use is confined to the manufacture of certain fuses and obscure decorative ornaments.

Juli L. Cook

New investigations of synthetic amethysts produced in Japan. Th. Lind and K. Schmetzer, *Journal of Gemmology*, Vol. 20, No. 5, 1987, pp. 274–277.

This article addresses further separations of natural versus synthetic amethysts. The authors focus specifically on the diagnostic properties of the synthetic amethyst produced in Japan, which differs from that produced in Russia (used in earlier studies).

The synthetic amethyst produced in Japan is characterized by fluid inclusions and two-phase inclusions, sharp lamellar structures connected with distinct color zoning (observed parallel to one rhombohedral face of the synthetic amethyst), and twinning confined to distinct areas of the synthetic crystal, all of which were observed with an immersion microscope. Furthermore, these synthetics exhibit the additional (albeit sometimes lower intensity) absorption band in the infrared area of the spectrum that previously has been observed to be characteristic of synthetic amethyst.

With the observations made in this study, the distinction of natural and synthetic amethyst continues to depend primarily on microscopic study of the specimen under immersion, most importantly for the observation of twinning features. Therefore, the authors recommend detailed knowledge of the various properties of polysynthetic twinning in natural amethyst based on the Brazil law. *Deborah Jean Martin*

Synthesis of rose-quartz crystal. M. Hosaka, T. Miyata, Y. Shimizu, and O. Okuyama, *Journal of Crystal Growth*, Vol. 78, 1986, pp. 561–562.

While the massive form of rose quartz is relatively common, crystals of rose quartz are rare in nature. This article reports on the synthesis of a rose-quartz crystal by hydrothermal growth. Using a seed crystal and pieces of massive rose quartz as a nutrient material, a crystal of colorless quartz was grown at 330°C from a titanium-containing alkali solution. The growth period was 10 to 14 days. The resulting colorless crystal was then heated at 1200°C in a platinum crucible containing calcium carbonate powder to which 0.5 wt.% iron was added. After heating, the colorless crystal turned pink and was semitransparent. These results suggest that the titanium was incorporated in the quartz crystal structure during hydrothermal growth, while the iron was incorporated during subsequent heat treatment. The results also support the Ti^{4+}–Fe^{2+} charge-transfer mechanism thought to give rise to the pink color of natural rose quartz. *EF/JES*

Synthetic alexandrite from USSR. C. Trossarelli, *La Gemmologia*, Vol. 11, No. 4, 1986, pp. 6–22.

The author describes synthetic alexandrite reportedly produced in the USSR. He examined 15 cut pieces (0.04–0.70 ct) and three semi-rough samples (94–117 ct). All of the sample stones exhibit pleochroism, fluorescence, and absorption spectra typical of alexandrite. The author points out the importance of crystallographic orientation in obtaining a good color-change effect (unfortunately, without further explanation). When examined with the microscope, cut stones exhibit flux "fingerprints," with occasional two-phase inclusions, as well as dark color concentrations that appear in straight lines. The cut samples are, therefore, believed to be grown by the flux method. The semi-rough samples, however, display curved striae and curved streams of bubbles. "Tailed" negative crystals, parallel tubular inclusions and flat included crystals are also common in this group. These three samples are believed to be grown by the Czochralski method. Thirty-two good-quality color photographs illustrate this article. *EF*

TREATMENTS

Colour and irradiation-induced defects in topaz treated with high-energy electrons. K. Schmetzer, *Journal of Gemmology*, Vol. 20, No. 6, 1987, pp. 362–368.

This second article by Dr. Schmetzer on irradiated blue topaz (the first was abstracted in the Summer 1987 issue of *Gems & Gemology*) purports to be "a detailed description of the coloration and different types of electron-induced defects in irradiated topaz." The study involved spectroscopic examination of parcels of Nigerian topaz that had been treated in a linear accelerator and then heated, topaz (of unspecified locality) that had been treated by gamma rays and high-energy electrons followed by heating, and other samples of topaz treated by neutron irradiation. Samples of naturally colored blue topaz from Brazil, Nigeria, and Zimbabwe were also studied for comparison. Coloration, color zoning, and pleochroism are described for the treated samples in some detail. A review of the color centers as determined from polarized spectra essentially summarizes the more complete description in Schmetzer's *Naturwissenschaften* article.

Photomicrographs accompany a discussion of cracks and needle-like defects associated with the various types of irradiation damage. Dr. Schmetzer concludes with explanations of how the defects observed in electron-irradiated blue topaz arise from charge build-up and differential thermal conductivity and expansion during the treatment process. *CMS*

Irradiated gemstones: Could the ice be hot? K. Nassau, *Lapidary Journal*, Vol. 41, No. 5, August 1987, pp. 41–46.

Although infrequently, radioactive gemstones have been reported in the jewelry trade. This raises the question of whether or not these stones represent a problem, and, if so, to what extent the industry should be concerned.

The purpose of irradiating gem materials is to intensify, produce, or change color. Many gemstones that reach the jewelry industry have been treated in this manner, and such stones do not present a hazard if the irradiation process has been performed properly. A reputable operator will check for significant radioactivity and will hold each parcel of irradiated gem material until the level is acceptable.

Nassau argues that gemologists should consider making a radiation check part of any gemological examination. Simple instruments are available to conduct such tests; the best known is the Geiger counter. To perform an accurate test, one should determine background radiation in the absence of the gem specimen.

Next, a reading should be taken of the stone. Any significant elevation above the background reading, in the author's opinion, should be considered undesirable, despite the fact that there are no official guidelines for permissible levels of radioactivity in gemstones. Included are two helpful tables: One lists the rays and particles used to irradiate gemstones, and the other describes the color changes that commonly result.

Juli L. Cook

Pa. jewelers rally to fight bill on treatment disclosure. J. Everhart, *National Jeweler*, August 16, 1987, pp. 14, 58.

Pennsylvania lawmakers are considering a piece of legislation, Senate Bill 497, that would require jewelers to disclose gem treatments at the point of sale. The Pennsylvania Jewelers Association (PJA) opposes the bill. They are not necessarily against disclosure, but they are concerned about the cost of compliance, the paperwork, and the provision that would allow the consumer to file charges against the jeweler within one year after the *discovery* that the "gem was treated and disclosure not made." The PJA contends that jewelers already provide treatment information and that, in the event disclosure is not made, current legislation covering misrepresentation and fraud also applies to jewelers. This interesting article gives some detail on how legislation evolves at the state level and the role a jewelry association can perform in the legislative process. *GAR*

MISCELLANEOUS

Mineral photography, film and lights. J. A. Scovil, *Rocks and Minerals*, Vol. 62, No. 4, 1987, pp. 258–262.

Mr. Scovil has added a new article to his series on mineral photography. In this installment, he primarily discusses film choices and lighting techniques as they affect mineral photography.

As in the previous articles, Scovil again incorporates his own "do-it-yourself" suggestions, such as the home-made photo-stand and the fiber-optic light source. These ideas are clever as well as helpful, since the photography of minerals is not an exact science and depends on the nuances of each individual piece. In addition, resorting to "do-it-yourself" techniques and equipment is often an economical way to achieve beautiful results.

Mr. Scovil also presents useful data, such as the color temperature of lights and the effects of lights on film. It would have been helpful to see a reference chart, and perhaps a few photographic samples of the ways in which light affects film. As it is, the article covers this topic quite well – with one notable exception: the problem of how to photograph color-change minerals such as alexandrite and change-of-color sapphire and garnet.

Noting the title of this article, one might have expected to see an expanded list of suggestions on the positioning of lights with regard to the mineral specimen. However, as this depends on the mineral itself, perhaps one should infer from the omission that experience and experimentation are the best ways to learn these subtleties.

For a beginner wishing to photograph minerals, this article, as well as the previous ones by Mr. Scovil, are invaluable. *Robert Weldon*

The glitter of Southeast Asia. R. Brus, *Diamond World Review*, No. 42, 1987, pp. 64–66, 68, 70.

Brus presents an interesting article filled with the history and tradition of the treasures of Southeast Asia. As far back as 1783, the Dutch were exporting $200,000–$300,000 worth of diamonds annually from Borneo's diamond mines. Not surprisingly, Bornean diamonds were used for centuries in state regalia and private jewelry. Much of the royal regalia has been put on public display in museums such as the National Museum of Jakarta and the Grand Palace in Bangkok.

Ornate costumes decorated with silver, gold, and precious gems were traditionally associated with power in Southeast Asia. The royalty also wore elaborate jeweled crowns, many of which were exceedingly heavy and uncomfortable. For example, the diamond-and-ruby coronation crown in Thailand weighs over 16 lbs.

The regalia of this region continues to be treated with great respect and tradition. Some objects are, to this day, offered fresh flowers, incense, and rice at least weekly, all of which adds to the glitter of Southeast Asia.

Barton C. Curren

The National Museum of Natural Sciences, Ottawa, Canada. J. D. Grice, *Rocks and Minerals*, Vol. 62, No. 5, 1987, pp. 321–327.

This installment of the magazine's "Collections and Displays" series features Canada's National Museum of Natural Sciences (NMNS). The author, division chief and curator in the mineral sciences division, begins with a brief history of the museum, starting from its inception in 1842. Highlights of the mineral collection are also included, illustrated with 14 black-and-white photographs. The collection emphasizes North American minerals, with approximately 50% of the more than 20,000 specimens being of Canadian provenance, and 25% coming from the United States.

There are 1,500 gemstones in the collection; again, the emphasis is Canadian, as Dr. Grice cites the necessity of purchasing stones at a "reasonable" price. The result is a diverse assemblage of rarely cut stones as opposed to the more commonly known diamond, sapphire, ruby, and emerald.

The article concludes on a hopeful note: Although very little of the collection is presently on display (one has the impression that this is due to lack of space), a permanent mineral gallery is planned for the future. Of particular interest is the fact that the NMNS has signed

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Suggestions for Authors

GEMS & GEMOLOGY is an international publication of original contributions (not previously published in English) concerning the study of gemstones and research in gemology and related fields. Topics covered include (but are not limited to) colored stones, diamonds, gem instruments, gem localities, gem substitutes (synthetics), gemstones for the collector, jewelry arts, and retail management. Manuscripts may be submitted as:

Original Contributions—full-length articles describing previously unpublished studies and laboratory or field research. Such articles should be no longer than 6,000 words (24 double-spaced, typewritten pages) plus tables and illustrations.

Gemology in Review—comprehensive reviews of topics in the field. A maximum of 8,000 words (32 double-spaced, typewritten pages) is recommended.

Notes & New Techniques—brief preliminary communications of recent discoveries or developments in gemology and related fields (e.g., new instruments and instrumentation techniques, gem minerals for the collector, and lapidary techniques or new uses for old techniques). Articles for this section should be about 1,000–3,000 words (4–12 double-spaced, typewritten pages).

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Daragh P.J., Sanders J.V. (1976) Opals. *Scientific American*, Vol. 234, pp. 84–95.

Liddicoat R.T. Jr., Copeland L.L. (1967) *The Jewelers' Manual*, 2nd ed. Gemological Institute of America, Santa Monica, CA.

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Color photographs—35 mm slides or 4 × 5 transparencies—are encouraged.

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