

Gemstones from the Laboratory

HISTORY

Humans have always sought to emulate nature and capture her secrets. The early alchemists, building on the dreams of antiquity, thought they could turn lead into gold. In like manner, the dream of creating valuable gemstones has inspired many attempts at the laboratory duplication of nature's crystalline masterpieces. Unfortunately, virtually all of these attempts were doomed to failure. You cannot recreate a complex feat of natural magic unless you understand the magician's trick. And a complete understanding of the structure and formation of natural crystalline solids, even with twentieth-century skills, remains elusive, although many parts of the puzzle have been solved.

However, the ultimate prize—to actually create valuable gemstones out of inexpensive chemicals, like turning base metal into precious metal—was tempting beyond imagination. In fact, as early as 1885, the first marketable gemstones were born in laboratory furnaces in France. Ruby had actually been made as early as 1837, but the material was not transparent or large enough for gemstone use. The work of Frémy and Verneuil opened the door to commercial sapphire and ruby manufacture, and by around 1902 the basic problems had been solved. An earlier gem, marketed in Switzerland and known as *Geneva ruby* has recently been shown to be a prior, successful product of the ruby-making procedure developed by August Verneuil.

Once it had been demonstrated that gemstones could be manufactured in commercial size and quality, a new era of intensive research was spawned. At this writing, the following gemstones (and approximate dates of first commercially viable production) have been manufactured: ruby (1885–1905); sapphire (1910); spinel (1910); star ruby and sapphire (1947); rutile (1948); emerald (1950,

1965); quartz (1950); diamond (1955; 1970); turquoise (1972); alexandrite (1973); opal (1974); lapis lazuli (1976); and jadeite (1984). Many other gemstones have been synthesized but await commercial exploitation.

Many of the techniques used to create gemstones in the laboratory were not developed to create misery for gemologists. The almost-magical science (some would call it an art) of crystal growth, almost exclusively a twentieth-century technology, is mainly concerned with crystals per se. Crystals are among the most important materials of civilization. In fact, nearly all of the things we take for granted today, including all forms of transportation, communication, banking, commerce, and manufacture, down to portable radios, TV sets, auto ignitions, and hearing aids, would not work at all without exotic, specially made crystalline materials. It can safely be said that the technology for growing crystals of these materials has become critical to the well-being of society. There is no aspect of daily existence in technologically advanced countries that is not influenced directly or indirectly by crystals.

Crystal growers make use of certain fundamental aspects of natural laws; these laws govern the states of matter and the interactions of atoms and molecules. One such law, known as the second law of thermodynamics, states that natural processes tend to run in a direction that produces the greatest entropy. *Entropy* is the degree of disorder, or randomness, of a system. The tendency of natural processes (that is, the direction in which things tend to go if left entirely to themselves) is to move in the direction of lowest energy. In other words, natural processes *spontaneously* go in a way that releases rather than absorbs energy. It turns out that energy is released when an atom or molecule attaches itself to an already-existing cluster of other atoms and molecules (a *nucleus*). The major focus of crystal growers is to use this principle in a

controlled way. All crystal growth methods boil down to an effort to alter the energy configuration of a chemical system very carefully; this would create the spontaneous change in the system that would cause randomly moving atoms to attach themselves to a nucleus, or seed crystal, fortuitously provided by the crystal grower. If everything goes according to plan, the atoms attach themselves slowly, deliberately, and in a way that follows the structural configuration of the seed crystal. The process continues until (1) there are no suitable loose atoms left to attach, or (2) the energy configuration of the system stabilizes and the *driving force* of the process ceases to operate.

One way to provide the driving-force energy is to change the temperature of the system. Another way is to change the number of loose atoms available, that is, the saturation of these atoms within the medium in which the crystal is growing. These two general techniques—changing temperature or changing saturation—are the basic methods by which nearly all laboratory-produced crystals are grown. These are also the two chief methods of crystal growth in natural environments.

CRYSTAL GROWTH

A crystal is characterized by long-range order; that is, the atoms in a crystal are arranged in regular, periodic arrays or patterns (like wallpaper). The object of crystal growth is to add more atoms and perpetuate the pattern. A *seed* crystal is used to provide the basic template, and the *raw material* (loose atoms) remains mobile by being vaporized, melted, or dissolved in a solution. Thus, we may speak of *vapor growth*, *melt growth*, *flux growth*, or *solution growth*, depending on the medium used for crystallization. Crystal growth is achieved by forcing the unattached atoms in the growth medium to attach themselves to the seed. This is theoretically relatively simple to do. All that is required is to cause the growth medium to contain more unattached atoms than the medium can handle at a specific temperature. Unfortunately, it is not so easy to make the atoms go exactly where you want them to go. This is why some people speak of the “art and science of crystal growing.”

In human societies, when cities become too crowded there is an exodus to the suburbs. If a growth medium, let's say a solution, is forced to contain an excess of dissolved material at a given temperature, the energy of the system may *become* out of equilibrium at a *lower* temperature. The direction of *spontaneous* change, the one that results in a lower overall energy for the system, is that which dumps some of the dissolved material back out of solution. If the dumping tendency is strong enough (that is, a very rapid temperature drop) the atoms will actually coalesce into many small nuclei, even though the process of nucleation *absorbs* energy and is therefore

not favored by thermodynamics. The best alternative to this random, uncontrolled growth is to provide a template, or seed crystal, for the dumped atoms to join. Crystal growth is tricky; many things can go wrong.

In light of this, it is absolutely amazing that gems exist. A gemstone is a transparent and outwardly perfect crystalline mass, (ideally) free of visible imperfections or flaws, of uniform color and sometimes of immense size. It is difficult enough to grow such perfect crystals in a controlled laboratory environment. It is nothing short of miraculous that, given the randomness of natural environments, nature has been able to produce crystals large and perfect enough to yield gemstones. In some cases, humans have yet to figure out how mother nature, the magician, has even been able to pull off the trick!

Following is an abbreviated summary of the basic methods used to grow crystals. All of the gemstones being made in laboratories are made by one or more of these methods.

Vapor Growth: Substances best grown from vapor are those that pass directly from a solid to a vapor when heated or those whose components can easily be transported in vapor form. Materials that pass readily from solid to vapor are said to be *volatile*. In vapor-transport techniques, the desired substance reacts (usually at a high temperature) with another material, and the products of the reaction are even more volatile than the original substances. These newly formed products are moved to a new location, usually at a lower temperature, where they react in a reverse way to recreate the starting materials. If the procedure is done carefully, the reaction yields single crystals. Vapor-grown crystals are characteristically long needles or thin plates; in some cases crystal growth yields lacelike aggregates known as *dendrites* (for example, snowflakes).

Vapor-grown crystals include most metals, cadmium and zinc sulfides and arsenides, and various oxides. No gems are commercially grown in this way.

Melt Growth: Most natural crystals were formed in molten environments deep within the Earth. The sizes of the crystals (grains) in a rock and the way in which the grains have grown together are meaningful to geologists and tell a great deal about the cooling history of the rock. Gemstones, including olivine (peridot), feldspars and others, are occasionally cut from larger crystals in such igneous materials.

The general term for melt growth is *solidification*. Everyone grows crystals from a melt. Water, after all, is nothing more than molten ice, a crystalline solid that freezes (solidifies) at only 32°F. Snowflakes, although dendrites, are single crystals of ice. However, the ice cubes in your refrigerator are not. Uncontrolled freezing of a melt generally results in the formation of many tiny crystallites that all grow at the same general rate to fill up

the available space. An ice cube is thus a *polycrystalline aggregate*, consisting of a myriad of intergrown crystals. Poured ingots of molten metals crystallize in much the same way.

Growth from the melt is very convenient and requires relatively unsophisticated equipment in many cases. This method is unsuitable, however, for growing materials that contain water or volatile components; such materials decompose at their melting point. In technical language, a "congruently melting" material is one that does not change composition at the boundary between the solid and liquid state and can therefore be grown by one of the following methods.

The *Bridgman-Stockbarger Method* (Fig. 7) was developed around the same time by P. W. Bridgman (American), D. C. Stockbarger (German), and the Russians J. Obreimov, G. Tammann, and L. Shubnikov in the period 1924-1936. A specially shaped container is used, generally a cylindrical tube that tapers to a cone with a small point at one end. The tube is filled with powder of the desired crystalline material and lowered through a heater (radio-frequency or electrical resistance types are most common), pointed side down. The material in the tube melts, but the small conical tip is the first part of the container to emerge from the heater. In ideal circumstances (not all that difficult to achieve) the first bit of molten material to solidify forms a single crystal, rather than a polycrystalline aggregate. Further solidification continues as an extension of the pattern provided by this *induced* seed crystal, until the entire cylinder is frozen, and the container is filled with a single crystal.

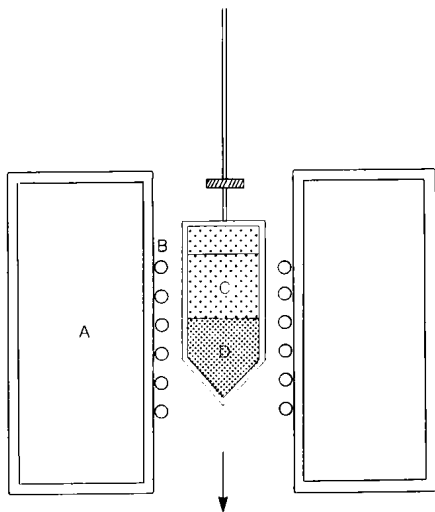


Figure 7. In the Bridgman technique, a specially shaped crucible, filled with a powder of the desired crystal (C), is lowered through a furnace (B). The powder melts and a crystal starts to form in the pointed tip of the crucible as the crucible emerges into a cool part of the furnace. A single crystal grows (D) as the molten material solidifies. The entire assembly is surrounded by insulation (A). Reprinted from Joel E. Arem, *Man-Made Crystals* (Washington, D.C.: Smithsonian Institution Press, 1973), p. 28.

There are many variations of this technique, some adapted for specialized applications such as the growth of high-purity metals. The method is extremely simple in concept and can be employed to grow truly immense crystals, the largest to date being more than 3 feet across and weighing more than a ton (sodium iodide, cesium iodide, and so forth). It is commonly used for the growth of halides, many sulfides, and a variety of oxides.

The *Verneuil Technique* (Fig. 8), or *flame fusion*, was developed in the late 1800s by August Verneuil, one of the great pioneers of gemstone synthesis. Verneuil had deposited sealed papers with the Paris Academy of Sciences in 1891 and 1892. When opened in 1910, these documents revealed the details of Verneuil's work on ruby synthesis, opening the door to large-scale production. The equipment detailed by Verneuil was so cleverly designed that modern factories still employ furnaces with essentially the same specifications as the original. Perhaps several hundred materials have been grown by the Verneuil method, and it is one of the least costly of all crystal growth techniques.

The Verneuil torch is an inverted oxyhydrogen blow-

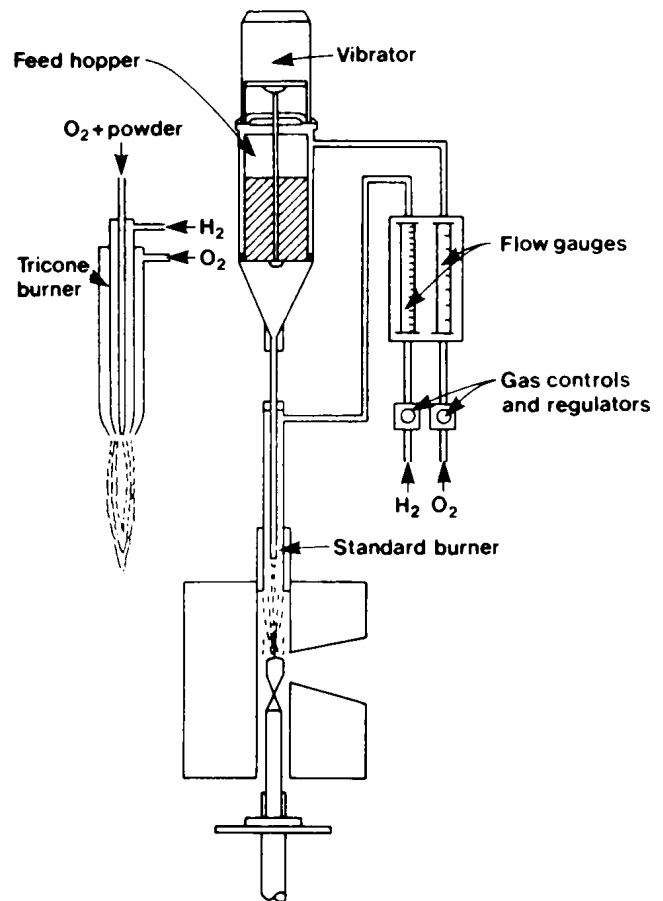


Figure 8. Diagram of the Verneuil furnace; the tricone burner (left) is used for many synthetic stones. Reprinted from Michael O'Donoghue, *A Guide to Man-made Gemstones* (New York: Van Nostrand Reinhold, 1983), p. 24.

torch; a powder of the substance to be grown is dribbled through this flame, and the molten drops fall onto a rotating rod, which is slowly withdrawn. The withdrawal rate is adjusted carefully, so that the molten droplets raining onto the rod solidify in a controlled fashion and build up a single crystal. The purity of the finished crystal is a function of the starting powder and the atmosphere in which the crystal is grown. The quality of the Verneuil crystal, or *boule* (French for *ball*) depends on the purity and particle size of the feed powder, the flame temperature, rate of rotation and withdrawal of the seed rod, and the shielding of the crystal from drafts. Verneuil-type crystals have also been grown using different heat sources, such as plasma arcs and parabolically reflected carbon arcs (*arc-imaging* technique).

The popularity of the Verneuil method for crystal production is illustrated by the fact that, by the 1920s, factories in Europe were turning out hundreds of millions of carats of Verneuil crystals annually. Among the gem materials produced commercially in this way are sapphire, ruby, star corundum, spinel, rutile, strontium titanate, and a vast array of oxides and other compounds.

The *Czochralski technique* (Fig. 9), or *crystal pulling*, was originally developed to measure the speed of crystallization of metals. It is now as important as the Verneuil method in gemstone crystal growth. The technique involves the melting of a starting powder in a crucible, generally platinum, iridium, graphite, or ceramic. A rotating rod with a tiny seed crystal on the end is lowered into the crucible until it just touches the melt, and then is slowly withdrawn. Crystallization at the interface between the melt and the seed proceeds in two ways: (1) Surface tension pulls some of the melt slightly out of the crucible onto the seed. Once this material leaves the melt, it cools just enough to solidify, adding to the seed crystal. (2) Also, heat conduction allows the solid to extend very slightly into the melt, assuring that ample material is pulled out to make the growing crystal ever larger. Crystal growth continues in this way until the entire contents of the crucible have been pulled out and added to the rod.

The pull-rate is normally on the order of 1 mm to 10 cm per hour. Czochralski crystals can be enormous—the size of baseball bats! A number of technologically vital crystals, such as pure silicon, are grown by pulling, as are many materials that are cut as gems. These include ruby, sapphire, YAG, GGG, alexandrite, and a wide variety of unusual oxides.

There are several variations on the basic Czochralski method. One, the *Kyropoulos technique*, was developed by S. Kyropoulos between 1925 and 1935. It is best suited to growing crystals much wider than they are long. The temperature of the crucible is lowered downward from the seed, as opposed to the crystal being pulled out of the melt. In *zone growth* (zone refining) a movable heater actually moves the melt zone, while the container and contents remain motionless. Extremely high purities are

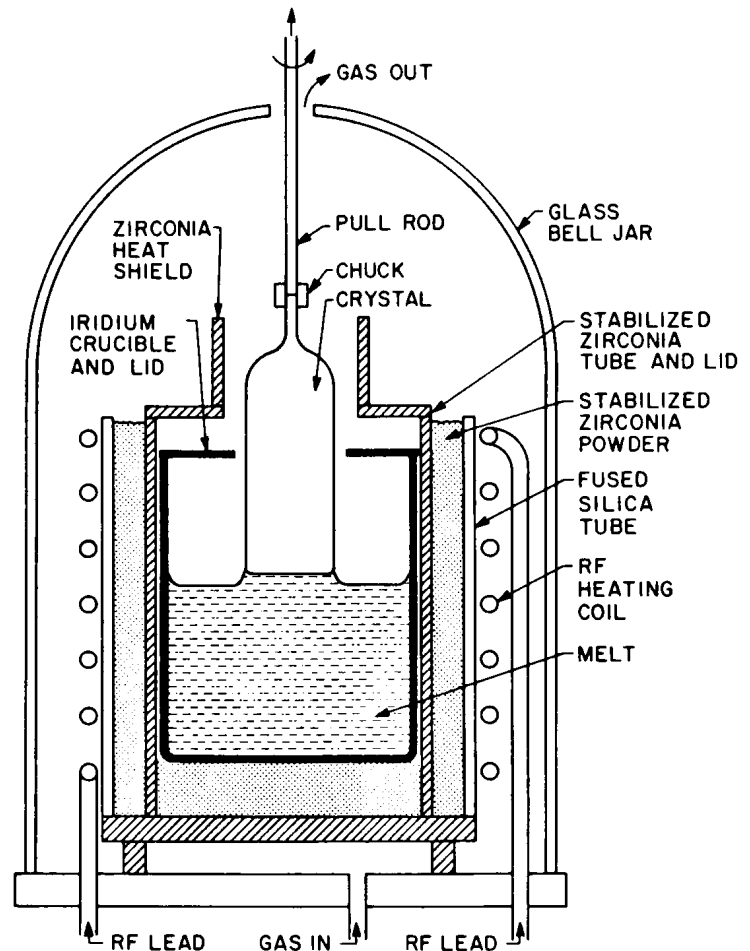


Figure 9. Apparatus for the Czochralski growth of large high-melting crystals such as synthetic ruby, YAG, and GGG; crucible diameter may be as large as 15 cm (6 in). Reprinted from Kurt Nassau, *Gems Made by Man* (Radnor, Pa.: Chilton, 1980), p. 87.

attainable in this way, as the moving melt zone acts as a kind of *impurity sweeper*.

Another variation, called *edge-defined film-fed growth*, allows crystals to be pulled through dies with shaped configurations; the growing crystal follows these outlines, resulting in continuous single crystals in the form of rods, sheets, tubes, and even more complex shapes.

A problem arises when materials are so reactive that they cannot be melted, even in such unreactive containers as platinum and iridium, or if the melting point of the material to be grown exceeds that of the available container materials. The latter is the case with cubic zirconium oxide (CZ) which melts at the fantastically high temperature of 2750°C. (4982°F.)

Single crystal growth of CZ was not managed until the 1970s, when a research group in the USSR perfected a technique (previously known) called *skull melting* (Fig. 10). The *skull* is an open-ended cup made of copper cylinders; the cup is filled with powdered zirconium oxide and heated by radio frequency induction until the powder melts. The region immediately adjacent to the

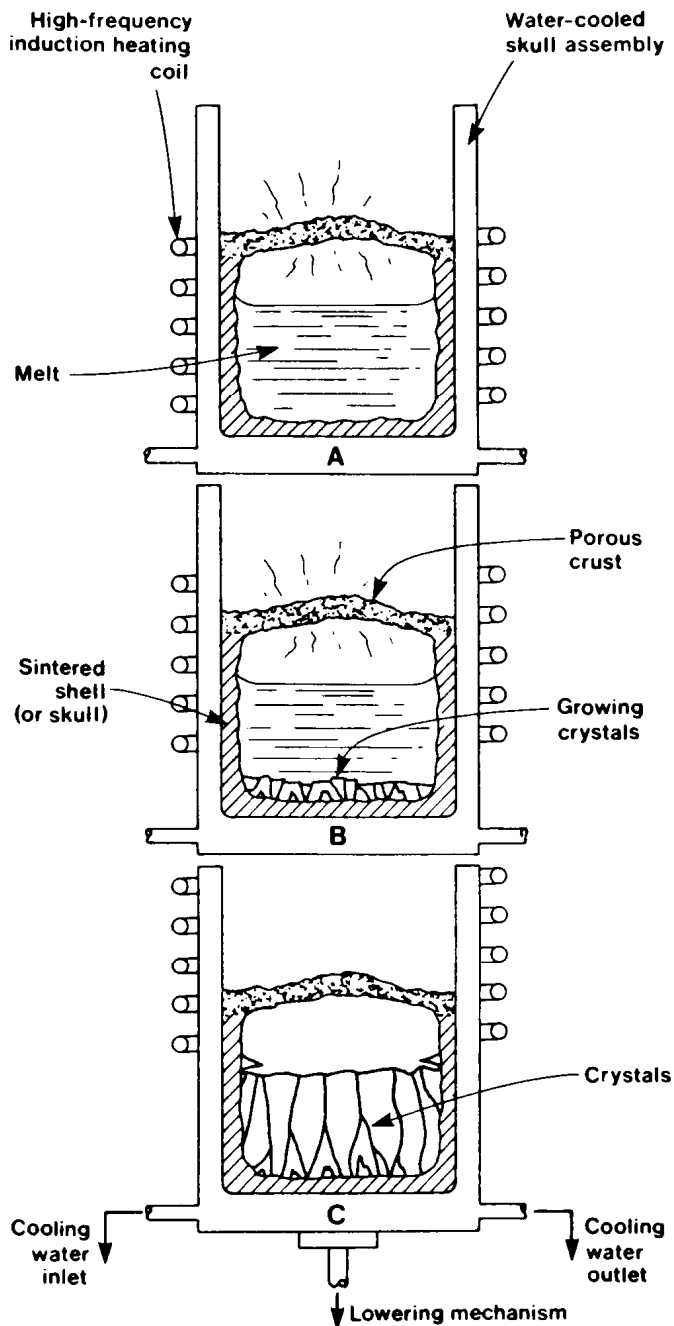


Figure 10. Skull melting (cubic zirconia). A: formation of a porous crust. B: growth of parallel columns. C: solidified melt. Reprinted from Michael O'Donoghue, *A Guide to Man-made Gemstones* (New York: Van Nostrand Reinhold, 1983), p. 59.

copper cylinders, however, remains solid because the cylinders are hollow and water cooled. The molten zirconia is thus effectively contained within a 1-millimeter-thick shell of solid zirconia. The entire assembly is allowed to slowly cool, and crystal growth proceeds by nucleation of parallel crystal columns until the entire mass has solidified. A typical skull contains about a kilogram of material, of which half emerges as cuttable CZ. At this writing, zirconium oxide (also hafnium oxide) is the only important gemstone material grown by this method.

Solution Growth: Solutions are perhaps the most familiar crystal growth environments. Even the simple act of making a cup of instant coffee is a study in solubilities, involving different rates and degrees of solubility of such widely different substances as sugar, powdered coffee, and saccharine. If you go swimming at the beach, the slippery uncomfortable feeling you get after awhile is the result of seawater evaporation, leaving a fine crust of sodium chloride and other salts on your skin. You can even see the crystal shapes (cubes in the case of sodium chloride) with a magnifying glass.

Solution growth has major advantages, including high mobility of dissolved components, convenience, and ease of control. The apparatus for solution growth can be as simple and inexpensive as a pot of water and some mason jars; most gemstones, however, require far more elaborate and expensive apparatus!

Although 5 pounds of sugar can be dissolved in a quart of boiling water, it is unlikely that such high solubilities can be found among oxides and silicates. In addition, although pure water is an excellent solvent for many compounds, the ones of gemological interest have such low solubilities that, for practical purposes, they may be considered insoluble. As in the case of natural environments, however, a bit of *mineralizer* (for example, sodium hydroxide) dissolved in hot water *dramatically* increases its capability for dissolving silicates such as quartz, beryl, and so forth. It is also much more effective to put the water under both high pressure and high temperature. Under these conditions, called *hydrothermal growth*, many mineral crystals can be duplicated in the laboratory. Moreover, since these are the same kinds of conditions that prevail in the ground, the resulting crystals often look strikingly like those found in ore deposits.

A major difference, however, is size. Nature is relatively unconcerned about the corrosion of container walls, the rupturing of growth vessels if the pressure gets too high, or even the exact chemistry (or purity) of the growth solutions. Very high temperatures and pressures are created with impunity. The result can be spectacular indeed: spodumene crystals up to 40 feet long, feldspars the size of railroad boxcars, and people-sized quartz crystals. To date the largest hydrothermal (quartz) crystals grown in laboratories weigh less than a few hundred pounds and are only a foot or so in diameter.

The growth of sugar crystals (rock candy) and other salts can be achieved at room temperature and pressure in simple containers. Silicates cannot be grown in this way. These substances can, however, be crystallized in steel cylinders called *bombs* (Fig. 12), which are loaded with feed material, water, mineralizers, and seed crystals and placed inside a sealed unit called an autoclave (Fig. 11). A hydrothermal growth apparatus is a pressure cooker. The bomb is heated within the device, and, since it is sealed, once the water in it expands to fill the cylinder, the pressure rises as the temperature is raised. The tem-

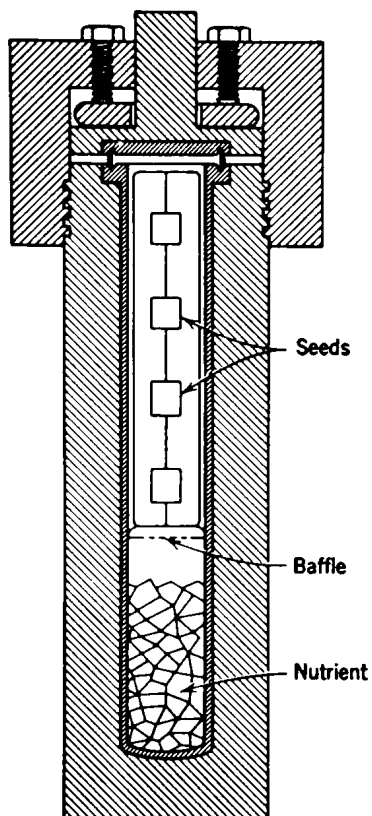


Figure 11. A silver-lined laboratory hydrothermal autoclave, about 35 cm (14 in) long. Reprinted from Kurt Nassau, *Gems Made by Man* (Radnor, Pa.: Chilton, 1980), p. 104. (Courtesy of A. A. Ballman and R. A. Laudise, Bell Laboratories.)

perature is carefully monitored, and the water added to the bomb exactly measured to achieve a predetermined pressure level.

Hydrothermal synthesis is not of great significance for technological applications, except in the case of quartz. It is, however, of tremendous importance for synthetic gemstones because so many natural materials form hydrothermally within the Earth. Among the gems produced in this way are emerald, amethyst, and citrine. Hydrothermal growth is especially suited to materials that contain water or other volatile components and that therefore decompose on melting.

Flux Growth: Water is an effective solvent for many substances familiar to us all. It is not, however, a powerful enough solvent to dissolve most oxides, silicates, and so forth. Ice is a crystalline solid that melts at 32°F. Other crystalline solids can also be melted at temperatures of only a few hundred degrees; if water is molten ice, what about the solution capabilities of other molten substances?

It turns out that a number of compounds, including borax, lithium oxide + molybdenum oxide, potassium fluoride, lead oxide and fluoride, and others are powerful solvents when melted; in fact, some crystal growers believe that it should be possible to find a molten-salt solvent for any given crystal. The earliest gem crystals, the rubies of Fremy, were grown from molten-salt solutions of corundum. A vast array of compounds can be grown in this way (Fig. 13), including alexandrite and emerald (Fig. 14), from molten salt (flux) solutions.

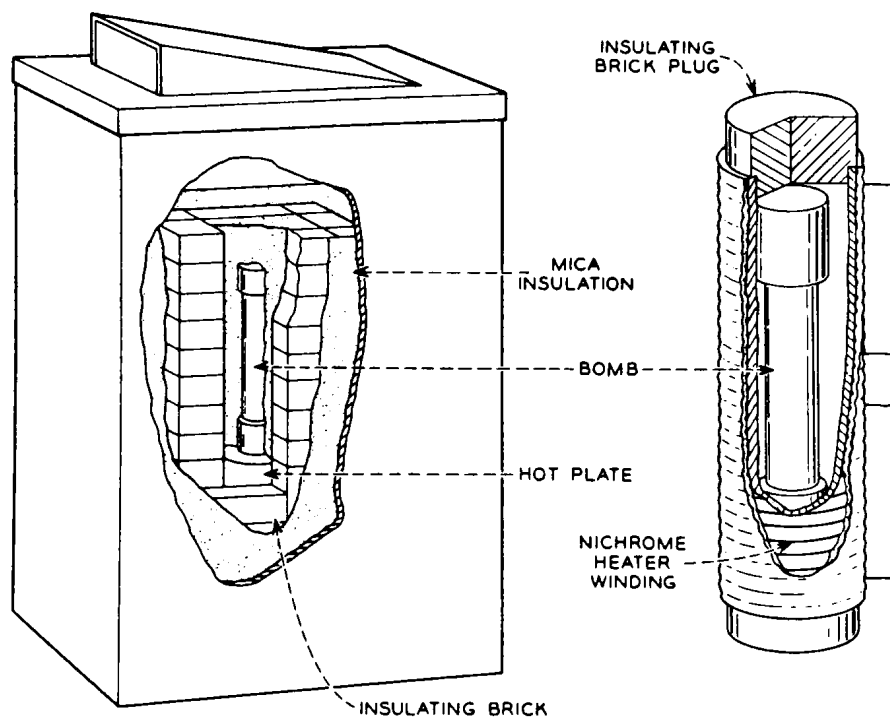


Figure 12. Enclosure and heating arrangement for a laboratory autoclave. Reprinted from Kurt Nassau, *Gems Made by Man* (Radnor, Pa.: Chilton, 1980), p. 105. Courtesy of A. A. Ballman and R. A. Laudise, Bell Laboratories.)

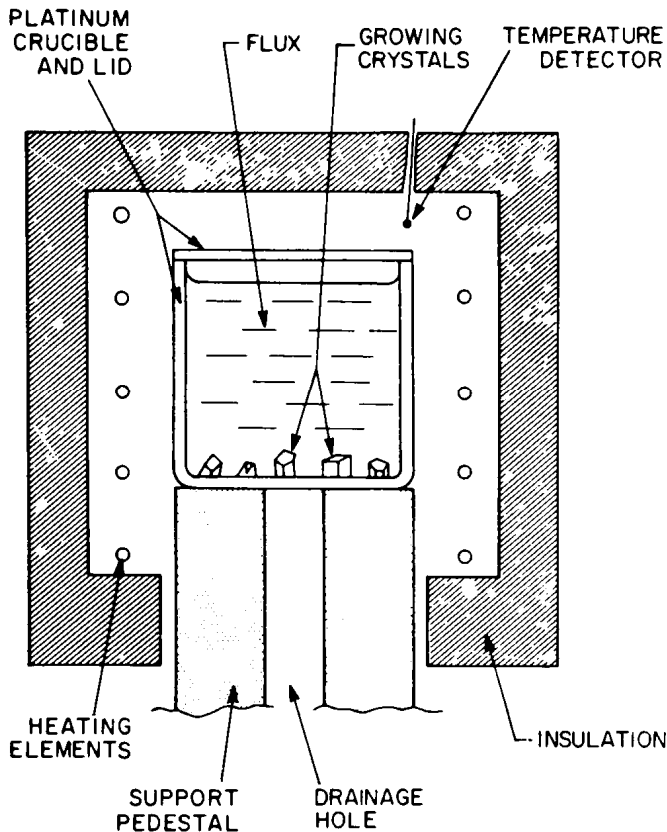


Figure 13. Crucible inside the flux-growth furnace. Reprinted from Kurt Nassau, *Gems Made by Man* (Radnor, Pa.: Chilton, 1980), p. 80.

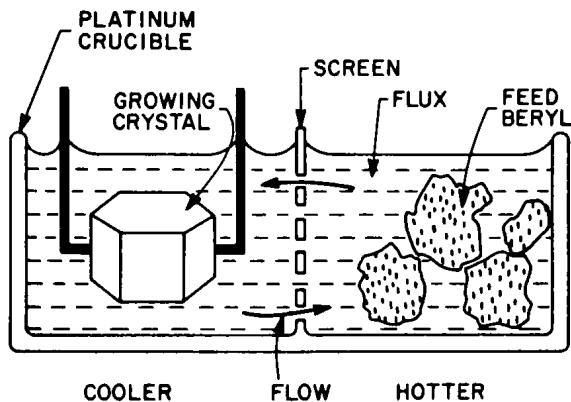


Figure 14. Schematic diagram of the flux transport growth of synthetic emerald used by Gilson. Reprinted from Kurt Nassau, *Gems Made by Man* (Radnor, Pa.: Chilton, 1980), p. 147.

Special Methods: The previous discussion encompasses the overwhelming majority of materials. However, some crystals require very unusual growth conditions (this was certainly true of cubic zirconia until skull melting became a commercial process!). Perhaps the most notable of these is diamond.

Diamond is a product of extremely high temperatures and pressures, conditions chiefly found in the Earth's

mantle at a depth of 15 or more miles below the surface. The major obstacle to diamond synthesis was finding (1) equipment that could produce these conditions, and (2) materials to use in making this equipment that would allow the equipment itself to survive (and maintain) these conditions! Success was claimed often in the period 1850-1950, but never truly documented. Unquestionable proof of diamond synthesis was, in fact, not forthcoming until 1955, when scientists at General Electric Co. announced a breakthrough. A 1,000-ton press achieved a simultaneous temperature of 5,000°F and pressure of 1.5 million pounds per square inch. Diamond forms from carbon very quickly (seconds to minutes) at these conditions, and so the production of synthetic diamond for industrial purposes is now routine, with millions of carats produced annually. However, the production of large, transparent diamond crystals suitable for gemstone use remains technologically elusive, and very expensive. A major breakthrough in this area could well be the most significant development in gemstone synthesis in history. It is not pure fiction to imagine that such a breakthrough could occur within a decade, since gem quality crystals up to about 1¼ carats have already been made.

DEFINITIONS

It is important to clarify the terminology associated with laboratory-produced gemstones since some confusion exists in the literature.

The International Committee on Technical Terminology (ICTT) in 1974, after three years of meetings and deliberations, proposed the following definitions:

Synthetic (n.) A human-produced chemical compound or material formed by processes that combine separate elements or constituents so as to create a coherent whole; a product so formed.

Synthetic (adj.) Pertaining to, involving, or of the nature of synthesis; produced by synthesis; especially not of natural origin.

Homocreate (n.) A human-produced substance (solid, liquid, or gas) whose chemical and physical properties are within the range of those possessed by the specific variety of the natural substance that the *homocreate* is intended to duplicate.

Homocreate (adj.) Synthetic and possessing chemical and physical properties that are essentially the same as those of its natural counterpart; created the same as.

A substance such as emerald, made in the laboratory, is a *homocreate*. Its properties are specifically designed to mimic those of the equivalent substance produced by nature. However, cubic zirconia, GGG, and YAG are true *synthetics*—simply compounds made in the laboratory, put together from components. They have no natural counterparts and are used as gemstones based on

their own meritorious properties. In other words, all homocreate materials are synthetic; but not all synthetics are homocreate.

These definitions were unanimously approved by the ICTT and have been adopted by most professional scientific societies. If gemology is ever to consider itself a true science, it will only do so if it begins to walk in step with other disciplines having a much longer history of empirical and theoretical evolution.

CHARACTERISTICS

Each crystal-growing method is somewhat unique and uses different equipment, chemicals, containers, and so forth. Natural crystals also grow in a wide variety of physical and chemical environments. Every crystal-growth process leaves its mark on the growing crystal in the form of color zones, inclusions, surface shapes, and so forth.

At any given moment during the growth of a crystal the surface is characteristic of both the environmental conditions and the growth process. As material is added to this surface, the newly added layer becomes the new outermost layer. We can therefore say that crystal growth is characterized by a succession of surfaces, and a crystal's history is documented by the record of its surfaces, in a way very analogous to tree rings. Moreover, crystal-growth environments are seldom absolutely pure. Contaminants may enter the growing crystal and be trapped within it; these may be chemical impurities or sometimes crystals or bits of foreign substances. Even the kinds of surfaces bounding the crystal during growth are characteristic of the growth process. Many of these features are visible, with correct illumination, under a microscope. Microscopy is therefore unquestionably the most powerful working tool for the gemologist who wishes to distinguish between natural and synthetic materials. This is especially important because most homocreate materials have properties almost identical to their natural counterparts, or properties within the range observed for the natural substances. Easily measured properties such as refractive index, specific gravity, emission spectrum, optic sign, even color, are not always definitive in identifying homocreates.

Also, the range of materials and growth methods used today is so vast that considerable experience is required to make positive identification. Crystal inclusions may be so small that magnifications up to 50× or more are required to see them properly; such inclusions may be the only proof of natural versus synthetic origin. Some gemstones, such as amethyst and citrine, are extremely difficult to distinguish, and in some cases identification is impossible. The value of a gemstone in the marketplace is largely a function of rarity, a feature not typical

of synthetic stones. The marketplace has expressed great concern over the issue of nondetectable synthetics and their impact on gemstone prices. To be sure, a nondetectable homocreate would be a serious problem if no tests could be developed to recognize it. It must be realized that pecuniary interests drive *all* markets. In the past few years the emphasis has been heavily weighted toward *making* good homocreates since the monetary return for success is immense and *far* greater than the reward for developing new detection methods. In other words, you can make a lot more money fooling the marketplace with a newly created gemstone than by selling instruments to detect these gemstones. The gemological field has a lot of catching up to do.

We must recognize that a certain (it is hoped small) percentage of homocreate gemstones will escape detection and enter the marketplace as natural gemstones. If this percentage is not too great, the market will not be adversely affected. It is only when a large portion of a marketplace is affected by created gemstones that problems may arise. The pattern seems to be one of increasing awareness, not only among gemologists but also in the public sector. Awareness is the most important aspect of this problem. *Most* gems can be proven to be either natural or synthetic. The *real* danger is in not being suspicious enough to have the stone tested in the first place.

Following is a brief summary of the characteristics typical of various homocreate and synthetic gems produced in laboratories. It must be remembered that overlap in features is common, and single characteristics, with a few notable exceptions, are seldom sufficient for positive identification.

Vapor Growth: This is not of major importance for gemstones. The most obvious feature might be dendritic patterns or zoning.

Melt Growth: Some techniques, such as Bridgman-Stockbarger, would leave virtually no identifying characteristics. Czochralski and Verneuil crystals, however, have such rapid growth rates that certain features become apparent. Melt growth is typified by rounded surfaces versus the plane surfaces found in natural crystals. These are observed as faint (sometimes distinct) lines visible with correct lighting. If you want to see what these so-called *curved striae* look like, take a telephone book, bend it slightly, and look at the side with a 2× magnifying lens. The image of a stack of gently curved parallel lines is very similar to the series of parallel bands (actually the series of former surfaces of the growing crystal) seen in most Verneuil crystals. Curved striae are instantaneous proof of synthetic origin. They are never found in natural crystals. Pulled crystals do not normally display such features. Instead, we may find tiny metallic inclusions that separated from the container used to grow the material

(for example, platinum) and occasional round bubbles. Round bubbles or tadpole-shaped bubbles with curved tails are also typical of melt-grown crystals and are positive identification features.

Solution Growth: This is a real gray area since natural crystals typically grow in hydrothermal solutions. The highest percentage of misidentified homocreates probably falls into this category. Experience, a good, high-powered microscope, and a suspicious nature are likely to be a gemologist's most useful tools. Multiphase inclusions (gas/liquid) are found in both natural and solution-grown crystals, although three-phase inclusions (solid/

liquid/gas) have not yet been duplicated in the laboratory in sufficient numbers to create identification problems.

Flux Growth: The most commonly observed feature is flux particles trapped in the synthesized crystal; these may resemble breadcrumbs or comets, clouds of dustlike particles, twisted veils, and so forth.

No single feature may prove diagnostic in some cases. Rather, the gemologist must rely on experience and a broad pattern of features for identification. Even so, it is common for some stones to defy analysis. The best rule of thumb is when in doubt, don't buy. If you pay the price for a fine quality natural stone, be sure it can be proven so.

BERYL—EMERALD

Formula: $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$ + Cr/V (trace of Cl in hydrothermal synthetics).

Crystallography: Hexagonal; synthetic crystals (depending on growth method) prismatic, equant, very thin tabular.

Color: Green (modified by yellow/blue).

Luster: Vitreous.

Hardness: 7.5-8.

Cleavage: Indistinct; fracture conchoidal to uneven; brittle.

color zones; strong color zoning; Starburst inclusions; dustlike flux, seemingly at surface of gem but actually inside the stone.

I.G. Farben/Zerfass: Phenakite inclusions; profuse twisted veils.

Chatham: Fingerprint veils; phenakite crystals; flux inclusions.

Hydrothermal:

Regency (Linde): Portions of seed crystals; phenakite crystals; daggerlike inclusions (nail heads); flattened healed cracks, with two-phase inclusions visible (high magnification); pointed hollow tubes.

	<i>Natural</i>	<i>Flux</i>	<i>Hydrothermal</i>	<i>Lechleitner Overgrowths</i>
Optics				
o	1.572-1.600	1.560-1.563	1.566-1.576	1.578-1.605
e	1.570-1.593	1.563-1.566	1.571-1.576	1.570-1.599
Birefringence	0.005-0.009	0.003-0.005	0.005-0.007	0.005-0.010
Density	2.68-2.78 (usually over 2.69)	2.65-2.67	2.67-2.71	—

Dispersion: 0.014

Pleochroism: Distinct: yellow-green/blue-green.

Luminescence:

LW: Gilson = mustard-yellow; Zerfass = weak red; Regency = bright red; Biron = inert; Lennix = red; V-beryl = inert; Crystal Research = inert; Seiko = green (distinctive); Chatham = medium to strong red-brown to red (Chatham stones transmit UV to 2300 whereas natural stones are opaque below 3000).

SW: Gilson = orange; others inert.

X-rays: Gilson = dull red.

Spectral: Strong and typical of natural emeralds. V-beryl (Australia) may show a weak band at 6100. Gilson material has a diagnostic line at 4270. Biron spectrum same as natural.

Inclusions*Flux Grown:*

Gilson: Veil-like feathers.

Lenix: Flux particles; two-phase inclusions resembling feathers.

USSR: Flux-void fillings and healed fractures (orangy brown).

Seiko: Flux inclusions, concentrated in a plane between

Lechleitner: Parallel color bands; dustlike particles; wedge-shaped two-phase inclusions parallel to growth direction; octahedral gold crystals.

Biron: Fingerprints; veils; fractures; nail heads with liquid and gas; two-phase large inclusions; white comet tails; gold particles; phenakite; growth features.

Crystal Research: Two-phase inclusions; color banding (in early material).

Inamori: Two-phase inclusions.

Comments: Synthetic emeralds typically have slightly lower refractive indices and birefringence than do natural stones. Flux-grown emerald does not show the infrared spectrum characteristic of water in the beryl structure. This infrared spectrum is characteristic only of natural and hydrothermal synthetic emeralds. Flux-grown emeralds typically have relatively low R.I., S.G., and show strong red fluorescence in UV. Chlorine appears to be a diagnostic trace element found *only* in hydrothermal synthetics. Other trace elements overlap with natural material and are therefore not diagnostic. Natural emeralds contain Na, Mg and Fe in significantly higher amounts

Tabulated Data on Synthetic Emerald

Source	e	o	Birefringence	S.G.
<i>Hydrothermal</i>				
Lechleitner				
Overgrowth	1.571-1.601	1.571-1.610	0.005-0.010	2.68-2.71
Solid	1.569	1.574	0.005	2.70
Beryl sandwich	1.566	1.570	0.004	2.68
Linde (= Regency)	1.566-1.572	1.571-1.578	0.005-0.006	2.67-2.70
Biron	1.569	1.573	0.004-0.005	2.68-2.71
Crystal Research (V-beryl)	1.571-1.575	1.566-1.570	0.005	2.68
Inamori (Kyocera)	1.563	1.568	0.005	2.65-2.70
<i>Flux</i>				
Gilson	1.558-1.561	1.565-1.575	0.003-0.005	2.65-2.70
Seiko	1.561	1.565	0.004	2.66
Lenix	1.562	1.566	0.004	2.62-2.65
Zerfass	1.555	1.561	0.006	2.66
USSR	1.559	1.563	0.004	2.65
Chatham	1.560	1.565	0.003-0.004	2.64-2.66

Notes: The Cr content of Lechleitner emerald is approximately 4-10% (weight), with mean R.I. varying from 1.576-1.605 as the Cr content increases. By contrast, Linde emerald has Cr = 0.3-1.2% and R.I. (mean) = 1.568-1.575. Natural emeralds usually have a maximum Cr content below 2%, but R.I. also varies with other impurities.

The properties of Seiko (flux-melt) emeralds are reported as similar to those of other synthetics.

Natural emeralds generally have contents of Na and Mg on the order of 1+ weight percent, whereas synthetic emeralds have very low concentrations of these elements.

(more than 0.1%) than synthetic emeralds but contain lower amounts (less than 18%) of silica and alumina.

Regency emerald is the material formerly made by Linde, manufactured under license by Vacuum Ventures, Inc. This material is therefore identical with the Linde product.

CHRYSOBERYL (Alexandrite)

Formula: BeAl_2O_4 (+ Cr/Fe).

Crystallography: Orthorhombic; synthetic crystals well formed.

Colors: Like natural alexandrite, violet-red/bluish green, depending on lighting source.

Luster: Vitreous.

Hardness: 8.5.

Density: 3.73 (flux); 3.715 (Czocharlski).

Optics: Biaxial (+).

R.I. = 1.746-1.755 (flux); 1.740-1.749 (Czocharlski).

Birefringence: 0.009 (flux, Czocharlski).

Dispersion: 0.015.

Pleochroism: Red/orange/green as for natural material.

Spectral: Transmission in two bands at approximately 4900 and 6700; this creates the alexandrite visual color change.

Luminescence: Czocharlski crystals fluoresce strong red in UV and X-rays. Seiko material also strong red under LW.

Inclusions: Layer of dustlike inclusions parallel to seed face; strong banding; wispy veils in flux-grown material. Pulled material may have tiny platinum crystals. Pulled alexandrite has been made in the USSR with crystals up to $100 \times 20 \times 10$ mm reported; these crystals vary in color with direction: cherry-red/blue-green/yellow-green. Seiko alexandrite is made by floating-zone growth, with crystals similar in shape to Verneuil boules; internal features (tadpolelike bubbles, and so forth) are similar to Verneuil. A general overall swirled appearance is distinctive.

Comments: Large crystals of alexandrite have been pulled from the melt by Kyocera of Japan. Flux-grown material has been marketed by Creative Crystals Co. of California. The melt-grown Seiko material is made by the same company that makes synthetic quartz crystals for Seiko watches. The color change is excellent and properties are generally comparable to those of natural alexandrite. A synthetic chrysoberyl (not alexandrite) has been grown hydrothermally in Czechoslovakia.

CORAL

Formula: CaCO_3 (Aragonite).

Crystallography: Orthorhombic; manufactured and sold as cylindrical, massive pieces.

Colors: Oxblood red, red, bright rose, salmon, angel's skin.

Streak: Dark red.

Luster: Translucent.

Hardness: 3.5.

Density: 2.43-2.70.

Cleavage: Grainy texture.

Optics: $N = 1.468-1.658$ (spot average = 1.55-1.58).

Luminescence: Weak purplish red where dye is concentrated.

Comments: This is a Gilson product. The grainy texture is due to the presence of particles of varying size. There are no growth features similar to those seen in natural coral. This material must be considered a coral stimulant or imitation. It effervesces (leaving a small residual red pigment) in HCl.

CORUNDUM

Formula: Al_2O_3 .

Crystallography: Hexagonal (trigonal); shape is a function of growth method.

Colors: Pure corundum is colorless; impurity-induced coloration is as follows: Pink/red (Cr); yellow-orange (Ni+Cr+Fe); yellow-green (Ni+Fe+Ti); green (Co+V+Ni) blue (Fe+Ti); purple/violet (Cr+Ti+Fe); alexandrite color change (V) gold (Cu); pink (Mn); gray (Fe); maroon (Co+Cr); yellow (Ni).

Luster: Vitreous to adamantine.

Hardness: 9.

Density: 3.97-4.1; typically 4.00.

Cleavage: None. Fracture conchoidal; slightly brittle; tough.

Optics: $o = 1.757-1.768$; $e = 1.765-1.776$; typically 1.762-1.770. Colorless Verneuil sapphire = 1.760-1.769. Uniaxial (-).

Birefringence: 0.008.

Dispersion: 0.018.

Pleochroism: As for natural corundum; dark red rubies with brownish tone (Kashan) show up very orangy.

Luminescence: May be stronger in synthetic versus natural stones. Synthetic rubies may phosphoresce after exposure to X-rays, although the Ramaura stones do not. This effect may be correlated with iron content, as synthetic rubies typically contain less iron than natural stones. SW: Rubies fluoresce, all types, weak to strong. Color may be orangy red or yellowish red (Chatham) also dull, chalky red (Ramaura, Lechleitner). Synthetic yellow sapphire is generally inert in UV light. Orangy stones colored by Mn and Cr may fluoresce deep red, and stones with Fe and V fluoresce orange. Chatham orange sapphire fluoresces weak orangy or yellowish red, blue sapphire patchy, uneven reaction in shades of chalky greenish/yellowish/brownish red, orange and yellow. Ramaura ruby dull chalky red to orangy-red, moderate, also chalky bluish-white zones. Lechleitner blue sapphire very weak chalky whitish blue.

LW: Fluorescence usually stronger in rubies than with SW, dull red, orangy red. Chatham sapphire fluoresces same colors LW as SW, but usually stronger. Ramaura fluoresces chalky dull red to orangy red, moderate to strong. Lechleitner blue sapphire inert in LW. Seiko *padparadscha* fluoresces strong red.

Spectral: Usually not diagnostic, as synthetic and natural stones exhibit much the same spectra. However, absorption bands at 4500, 4600, and 4700, all due to iron and visible in many natural yellow, blue and green sapphires, are not seen in synthetic stones.

Inclusions: Plato-Sandmeier effect between crossed polars (interference colors).

Verneuil: Curved striae (most characteristic), curved zones of small bubbles, swarms of gas bubbles, spherical gas bubbles, unmelted particles, strings of bubbles.

Geneva: Same as Verneuil, more bubbles, angular striations.

Frémy: Triangular inclusions, so-called coat hangers.

Early Hydrothermal: Natural seed with polysynthetic twin lamellae surrounded by synthetic coating; gas bubble trails and liquid feather fingerprints.

Chatham: Lacelike fingerprints, netlike mesh inclusions, disseminated Pt platelets. Dense white cloudlike areas; transparent crystals; fractures and healed fractures; Color zoning. Thin white needles. Flux inclusions in varying patterns.

Kashan: Flux inclusions (conclusive ID); parallel hoses and flux-drop inclusions; fine cloudlike or foglike veils.

The so-called hair-pins or comets of melt drops with long white tails are considered diagnostic for Kashan. Very tiny inclusions of cryolite also seem to be characteristic. *Ramaura*: Residual unmelted flux, angular or rounded, white to orange-yellow. Flat or wispy flux fingerprints; comet-tails, growth features, color zoning with wedge-shaped zones.

Knischka: Broad, dustlike clouds; liquid feathers; negative crystals, perched on the ends of long crystalline tubes (characteristic). Unusual two-phase inclusions at high magnification. Flux inclusions, Pt particles (hexagonal black plates).

Czochralski: Very fine striations occasionally seen, normally no growth features or inclusions.

Lechleitner: Flux fingerprints and wispy veils, ranging from transparent/colorless to opaque/white; curved striae. Higher concentration of inclusions in sapphire versus ruby.

Comments: Synthetic corundum was the earliest of the mass-produced gemstone materials to come from the laboratory. The existence of a ruby in an antique setting does *not* therefore guarantee natural origin, since rubies of sufficient size for cutting were grown a full century ago. Corundum is one of the easiest gems to grow and is amenable to perhaps the widest range of growth methods.

The properties of synthetic corundum are virtually identical to those of natural material. Therefore, optical measurements, luminescence, spectral data, and the like are all of limited usefulness in identification. As with the vast majority of synthetic products, the critical diagnostic features are inclusions. The evaluation of such features is almost an art and can only be performed by a skilled gemologist who has examined many natural and synthetic stones and is thoroughly familiar with their microscopic appearance. Even assuming such skills, a certain small percentage of synthetic stones are misidentified as natural, and in some cases the laboratories cannot make a positive identification either way. This percentage, at least at this writing, is small enough not to seriously affect the market for natural gemstones.

Star corundum is made by dissolving titanium oxide in molten corundum and cooling the material at a rate that allows the dissolved oxide to exsolve as needlelike crystals of rutile; these orient themselves in accordance with the trigonal symmetry of the host corundum. Reflections from these densely packed crystals produce the effect known as a star.

Luminescence is a useful diagnostic test; natural blue sapphires do not react to UV light, whereas many Chatham blue sapphires fluoresce a distinct pale greenish color in LW and dull green in SW. Verneuil sapphires tend to fluoresce whitish to milky green in SW.

Stone Sizes: The early Frémy rubies were thin, tabular crystals that were initially a few mm in size but eventually

were grown to a diameter of about 10 mm (though less than 1 mm thick). The so-called Geneva rubies marketed as natural stones between 1885 and 1903 were recently shown to be an early Verneuil-type synthetic; stones were generally only a few carats, as the boules were only about ¼ inch across. The flame-fusion boules grown by August Verneuil reached a length of only about 1 inch; however, modern factories, using updated versions of Verneuil's original equipment routinely produce boules 6 inches long and 1 inch in diameter, and ruby boules as long as 17 inches have been grown. Star corundum in a wide range of colors is also routinely grown. The stars in such material are exceedingly sharp and intense, which itself aids in distinguishing them from natural star rubies and sapphires. Internal stresses that accumulate during the growth of Verneuil crystals can be relieved only by allowing the boule to crack after it has cooled. Modern Verneuil factories contain as many as 250+ torches, and global Verneuil production capacity has been estimated at as much as a billion carats annually. Czochralski ruby crystals are true giants, reaching a size of up to nearly 10 pounds; colorless sapphire crystals grown for military purposes have reached a size of 22 pounds. Flux-grown rubies are typically an inch or two in diameter, and hydrothermal crystals seldom reach a size greater than 3-4 inches. A colorless sapphire crystal weighing more than 100 pounds was grown by controlled solidification in a crucible.

CUBIC ZIRCONIA = Phianite (+ Y) = Djevalite (+ Ca)

Formula: ZrO_2 (+ Y or Ca).

Crystallography: Isometric; crystals irregular due to growth process (skull melting).

Colors: Colorless if pure; many colors produced by dopant impurities (see table).

Cubic Zirconia Dopant Colors

Dopant	Color
Ce	yellow-orange-red
Co	lilac
Cr	olive green
Cu	yellow
Er	pink
Eu	pink
Fe	yellow
Ho	pink
Mn	brown-violet
Nd	lilac
Ni	yellow-brown
Pr	amber
Tb	brownish green
Ti	yellow-brown
Tm	pale green
V	green

Luster: Vitreous.

Hardness: 8-8.5.

Density: 5.5-6.0. C-Ox: green = 5.52; blue = 5.34.

Cleavage: None; fracture conchoidal to uneven; somewhat brittle (good wearability).

Optics: $N = 2.15-2.18$.

Birefringence: None.

Dispersion: 0.058-0.066.

Luminescence:

Y-stabilized material: weak reddish/greenish yellow in UV.

Ca-stabilized material: yellow fluorescence in UV.

Pink (Er-doped): yellow-green in LW, faint green in SW.

Lilac (Nd-doped): bright peridot green in LW, faint green in SW.

Orange (Ce-doped): red in LW.

Other doped colors inert.

Inclusions: Small gas bubbles; tiny solid inclusions, often in rows; clouds of tiny particles; striae (rarely).

Stone Sizes: Rough material is limited by the size of the growth apparatus; typical crystal fragments are on the order of 1×2 inches but could be made slightly larger if warranted; pieces up to $8 \times 3 \times 3$ cm are routinely made.

Comments: Cubic zirconia (CZ) is the most realistic and popular diamond simulant ever mass produced. It is so diamondlike in appearance that, when first introduced, it fooled many gemologists and jewelers who were not yet aware of its existence in the marketplace. However, it is quickly and easily distinguished from diamond by thermal conductivity (which is much greater in diamond than in CZ). Special devices such as the Ceres Diamond Probe, distributed by the leading domestic manufacturer of CZ, were created especially for the purpose of separating diamond from its simulants.

Zirconia is the only synthetic gem material routinely made with skull-melting techniques. This method uses a water-cooled crucible heated by radio-frequency induction. Careful temperature control allows the material immediately adjacent (perhaps a 1-mm thick zone) to the crucible wall to remain frozen, while the remainder of the oxide is molten. The frozen layer prevents the molten salt from attacking the crucible, and crystallization is achieved through slow cooling. The process yields irregular masses, not euhedral crystals.

Cubic zirconium oxide is, in fact, known as a natural material. It was discovered in 1937 during a routine investigation of some metamict zircons. The monoclinic form of the same composition is known as the mineral baddeleyite. Cubic zirconia is used widely in ceramics because of its high melting point. Pure zirconium oxide

melts at 2750°C . The cubic form does not crystallize from a melt of pure composition but can be stably produced (and preserved as the cubic modification down to room temperature) by adding stabilizers such as oxides of Ca, Mg, or Y to the melt. Single crystals of cubic zirconia were first grown in 1969, but these were very small (about $\frac{1}{2}$ inch). An enlarged version of the 1969 apparatus later produced much larger crystals, and when cubic zirconia gems were introduced into the marketplace in 1976, all previously used diamond imitations (YAG, GGG, and so forth) become obsolete.

DIAMOND

The properties of synthetic diamond are essentially identical to those of the natural material. Even the various types of naturally occurring diamond (Ia, Ib, IIa, IIb) that differ in composition and conductivity have all been synthesized.

Attempts to synthesize diamond were made as long ago as 150 years. A full century of experimentation proved fruitless, mainly because the pressure and temperature conditions under which diamond forms could not be attained with apparatus available during this time period. Diamond readily forms from carbon at a temperature over 4000°C and a pressure between 1 and 3 million pounds per square inch. These awesome conditions, which prevail in the Earth's lower crust or upper mantle (where diamonds form in nature) can only be duplicated in the lab using specially prepared steels and alloys and cleverly designed equipment, largely pioneered by the Harvard University scientist-philosopher, Percy Bridgman. In 1954 H. Tracy Hall, a scientist with General Electric, became the first person to verifiably produce diamonds. The G.E. team included Hall, F. P. Bundy, H. M. Strong, R. H. Wentorf, J. E. Cheny, and H. P. Bovenkerk. The initial crystals were quite small, but in 1970 G.E. made crystals up to about 1 carat in size, which yielded cut stones from about $\frac{1}{4}$ to $\frac{1}{2}$ carat, in various colors including yellow and blue. Some of these cut stones and crystals were donated in 1971 to the Smithsonian Institution for its permanent collection.

The shape of synthetic diamond crystals depends on the temperature of formation, and may be cubes, octahedra, dodecahedra, or combinations of these forms. The addition of B, as in nature, produces a blue color, whereas nitrogen dispersed in the structure gives yellow, brown, and green hues.

Free-world production of synthetic diamond is estimated at more than 100 million carats per year.

Distinguishing Features: G.E. synthetics are inert in LW ultraviolet, but in SW colorless synthetic diamond fluoresces strong yellow with persistent phosphorescence of the same color. Grayish-blue material fluoresces and phosphoresces slight greenish yellow; yellow material is inert in SW. Blue and near-colorless material may show a

cruciform pattern of fluorescence. Synthetic diamond appears to be characterized by strong short wave UV fluorescence and phosphorescence while remaining inert in LW.

Near-colorless synthetic diamond is electrically conductive; no such natural material has yet been reported. G.E. synthetic diamonds (made with iron-containing flux) also exhibit magnetic reaction, not seen in natural diamond. Inclusions in these stones include diffuse clouds of tiny pinpoints, and rounded, opaque metallic platelike or rodlike flux inclusions. G.E. synthetic diamonds appear strain free in polarized light.

There seem to be fundamental differences in the magnetic properties of natural versus synthetic diamond; this may form the basis of a distinguishing test when sufficient measurements are made to reveal statistically significant results.

GARNETS (YAG and GGG)

Formula: YAG = $Y_3Al_5O_{12}$. GGG = $Gd_3Ga_5O_{12}$.

Crystallography: Isometric; pulled cylindrical crystals for both YAG and GGG.

Colors:

YAG is colorless if pure; many colors are produced with various dopants:

Color	Dopant	S.G.	R.I.
colorless	—	4.56	1.832
green	Tb	6.06	1.873
pale yellow	Tm	6.48	1.854
yellow-pink	Er	6.43	1.853
pale yellow	Yb	6.62	1.848
pale yellow	Lu	6.69	1.842
yellow-green	Dy	6.20	1.85
golden yellow	Ho	6.30	1.863
pale green	Pr	—	—
lilac	Nd	—	—
green	Cr	—	—
red	Mn	—	—
blue	Co	—	—
yellow	Ti	—	—

GGG is colorless if pure; slightly impure material turns brownish on exposure to UV. Also red, blue, green, and so forth.

Luster: Vitreous for both YAG and GGG.

Hardness: YAG = 8.5; not brittle. GGG = 6-7.

Density: YAG = 4.55-4.57 (Ga-doped = 5.06-5.08). GGG = 7.02-7.09.

Cleavage: None; fracture conchoidal to uneven for both YAG and GGG.

Optics: For YAG $N = 1.83$ (Ga-doped = 1.90). For GGG $N = 1.92-2.03$.

Birefringence: None for both YAG and GGG.

Dispersion: YAG = 0.028. GGG = 0.038-0.045.

Pleochroism: None for both YAG and GGG.

Spectral: Typical R.E. spectrum from dopants for YAG and GGG. YAG also has Cr lines if Cr-doped.

Luminescence: For both YAG and GGG, colorless material fluoresces strong yellow in LW, weaker in SW. Bright glow in X-rays.

Stone Sizes: Czochralski crystals of YAG pulled up to approximately 2 × 8 inches or about 4 pounds. Czochralski crystals of GGG pulled up to approximately 4 × 12 inches or about 35 pounds.

Comments: True synthetic analogs of natural silicate garnets are difficult to make in the laboratory, have little technological interest, and have been grown only in very small sizes. However, a huge family of technologically vital compounds with the garnet structure exists, and many of these are commercially manufactured on a large scale. These materials fit the general formula $A_3B_2C_3O_{12}$ (or $A_3B_5O_{12}$ if B and C are the same element). Many are compounds of rare earth elements. Variations in both the basic chemistry and dopant impurities can lead to a vast range of colored crystals with gemstone potential.

The first of these garnet-structure oxides were grown by the flux method. A very important material, $Y_3Fe_5O_{12}$ (yttrium iron garnet, = YIG) is vital to microwave devices and computer bubble memories. This compound is jet black. However, two useful laser materials, yttrium aluminum garnet (YAG) and gadolinium gallium garnet (GGG) were recognized as early as 1962 as having gemstone potential. Highly perfect YAG crystals doped with Nd were grown from the melt by Czochralski methods in the late 1960s. As a result, colorless and doped YAG became widely available at a low enough cost to stimulate gem use.

Oxides of GD and GA are much more expensive than that of yttrium. Moreover, GGG, if even slightly impure, turns brownish on exposure to ultraviolet light (for example, sunlight). These factors, plus a high specific gravity, have limited the gemstone use of GGG. YAG was the dominant diamond imitation of the 1960s and 1970s, essentially completely replacing rutile and strontium titanate in this role. All such simulants were supplanted by cubic zirconia by 1976, so the popularity of both YAG and GGG were short lived. YAGG (Ga-doped YAG) resembles tsavorite and is also grown from flux. These gems have natural-looking feathers and crystals. Pulled crystals tend to have twisted, droplike inclusions as well as black crystals with square and triangular shapes.

JADE

Formula: $NaAlSi_3O_6$.

Crystallography: Monoclinic.

Colors: Colorless, green (Cr), lavender (Mn), greenish gray, yellow, black (excess Cr). Addition of TiO₂ aids whiteness and translucency.

Luster: Vitreous.

Hardness: 6.5-7.

Comments: Researchers at General Electric produced jadeite discs, in various colors, within a high-pressure cell. The starting material was a mixture of oxides first melted to a glass, then reground and recrystallized within the jadeite P-T stability field. An alternative method was to grind up and recrystallize (with chemicals added to produce the desired color) natural jadeite. Times involved ranged up to 24 hours. Discs up to ½ inch diameter and ⅛ inch thickness were produced, but the size could be increased by using larger apparatus. The researchers projected that *Imperial* quality jade could be produced with this method. The details were published in 1984.

A little-known patent dating back to 1951, however, detailed a process for making synthetic materials to serve as an ideal jadeite simulant. Insufficient information is presented to know whether a true homocreate product was made. The S.G. of this material was given as 3.2-3.8, hardness 6-7, soapy-waxy feel, and colors included white, brown, green, yellow, black, and blue.

An amorphous material called *Siberian jade* or *reformed jade*, manufactured in Japan, is dark green with a hardness of 5-5.5, S.G. = 2.67, and $N = 1.523$ (anomalously anisotropic), with absorption bands at 4000-4600 and 6000-7000. Inclusions observed in this material include needles of apatite and dendrites.

The G.E. jadeite could pose serious detection problems if made in larger sizes. The look of the finished product is strikingly like that of natural jade; microstructures are slightly different, with the synthetic having a glassy-looking second phase present at grain boundaries, visible under very high magnification (300-500×). Apparently the composition of the mixture must be precisely controlled to prevent the formation of this glassy phase, a problem that may also account for the extreme rarity of translucent or transparent natural jadeite.

LAPIS LAZULI

Formula: Na₈(AlSiO₄)₆S₂ (= synthetic ultramarine).

Crystallography: Cubic; cryptocrystalline—granular texture.

Colors: Dark blue, violet-blue—comparable to the finest natural lapis.

Hardness: 5.5-6 (natural lapis = 5.5).

Density: 2.46 (average); material is somewhat porous (natural lapis = 2.81). Range 2.40-3.0.

Cleavage: None; fracture uneven.

Optics: $N = 1.50-1.55$ (spot).

Birefringence: None.

Spectral: Not diagnostic.

Luminescence: Inert; calcite inclusions, if present, may fluoresce pink in LW.

Comments: The Gilson product reacts much more readily to sulfuric acid than natural lapis, with effervescence and sulfurous fumes evident. It is also decomposed by HCl. The material is quite porous (as much as 5.7% porosity) and the density is consequently much lower than natural lapis. Natural, crushed pyrite is added to the Gilson product to make it more natural looking. The pyrite in natural lapis, however, is far more irregular in shape than the rounded grains in Gilson material and is not as evenly distributed in the rock. Pyrite in Gilson lapis also tends to pull out of the matrix during polishing, a characteristic almost never observed with natural material. Gilson makes lapis both with and without pyrite.

The Gilson material consists of synthetic ultramarine plus two hydrous zinc phosphates. It has therefore been suggested that this material be termed an *imitation lapis* rather than a homocreate material.

OPAL

Formula: SiO₂ · nH₂O.

Crystallography: Noncrystalline (amorphous); aggregate of submicroscopic silica particles.

Colors: Colorless, white, as made in the laboratory, with variable play of colors produced by diffraction effect. Body colors produced also include gray, black, yellow-brown.

Luster: Vitreous, pearly.

Hardness: 4.5-6+ (natural opal generally 5.5).

Density: 1.91-2.24 (Gilson); 2.20 (Inamori).

Cleavage: None; fracture conchoidal; brittle.

Optics: Isotropic; $N = 1.41-1.45$ (Gilson); $N = 1.46$ (Inamori).

Birefringence: None.

Luminescence:

SW: strong chalky yellow-green diagnostic for Gilson. Faint yellow fluorescence in Inamori. Gilson orange opal fluoresces bluish white.

LW: Faint or no reaction, except Gilson orange *fire opal* may be dull blue or green.

Inclusions: Occasional gas bubbles. Distinctive cellular chicken-wire or snakeskin pattern is diagnostic of Gilson opal; also seen in Inamori.

Comments: An opal-like material with good color play has also been made in Japan, consisting of plastic spheres about 220 nm in diameter, and bonded with plastic. The

color play of this material arises in the same way as in natural opal, that is, diffraction from layers of uniformly packed spheres of constant size; in the case of the plastic opal, however, the spheres are not silica but polystyrene. The R.I. is 1.485 (corresponding to that of an acrylic coating on the polystyrene matrix), sometimes with anomalous birefringence, and the S.G. = 1.19. Both LW and SW give a whitish fluorescence. Tradenames such as *Pastoral Opal* and *neo-noble opal* have been used in conjunction with these plastic imitation opals.

Gilson material contains distinctly less water than natural opals; white Gilson synthetic also contains measurable amounts of ZrO_2 and in some cases organic materials. Gilson opal is like natural opal to the unaided eye, but differences are apparent under magnification.

QUARTZ

Synthetic quartz has virtually identical properties to natural material. In fact, it is perhaps the one synthetic for which no really satisfactory diagnostic test exists to separate it from natural material. Inclusions that are clearly natural in origin, or some kinds of twinning, are the only proof of a natural stone.

Quartz is a vital electronic material because of its characteristic *piezoelectricity*, that is, pressure applied to a slice of quartz crystal produces an electric current, depending on the orientation and thickness of the slice. Conversely, an alternating voltage applied to such a quartz slice causes it to vibrate. This effect is valuable in communications equipment and oscillators, such as the ones used in crystal watches.

Production of synthetic quartz was deemed vital to U.S. security during World War II, but perfection of the required technology escaped American researchers. Following the war, notes and equipment seized from the German laboratory of Dr. Richard Nacken provided the missing clues, and by 1950 quartz manufacture, centered in Ohio, was a commercial reality.

All synthetic quartz is manufactured using hydrothermal transport techniques. The feed material is natural quartz, and the transport medium is an alkali-rich water solution superheated under pressure in an autoclave. Crystals weighing about 15 pounds are routinely produced, but giants as large as 40 pounds have also been made with production equipment.

Colored Quartz: Colorless quartz of high purity, although technologically valuable, has minimal value as a faceted gemstone. However, colored quartz gems are a staple of the commercial marketplace and are extremely popular due to widespread availability and low cost. Colorless quartz is amazingly pure. Colors are created by minor amounts of impurities, coupled with the effects of irradiation, typically using cobalt-60. The following treatment processes are widely understood and used commercially:

Q + Fe = brown/yellow;

Q + Fe + heat = green;

Q + Fe + irradiation = violet (amethyst);

Q + Co + heat = blue;

Q + Al + irradiation = dark brown;

Q + irradiation + heat = yellow-green;

where Q = colorless quartz.

Large amounts of synthetic citrine and amethyst are made commercially in the USSR and Japan; the chief U.S. manufacturer is Sawyer Research Products Co. of Cleveland, Ohio. However, the most important synthetic amethyst and citrine in the marketplace today is that from Japan. It is hydrothermal and very difficult to distinguish from natural material. Japanese synthetic quartz has liquid-filled feathers and two-phase inclusions, sharp growth zoning parallel to one rhombohedral face, and unique twin structures that are different in appearance from the polysynthetic lamellae seen in natural amethyst. The chief distinguishing test for natural vs. synthetic amethyst is the appearance of twinning in crossed polarized light.

RUTILE

Formula: TiO_2 .

Crystallography: Tetragonal.

Colors: Near colorless (slightly yellowish); orange, brown, red, blue, green, black. Rutile boules slightly deficient in oxygen are blue-black as grown, but turn slightly yellowish when annealed in oxygen. Light blue colors are the result of oxidation after growth. Yellow-red-amber colors are produced by adding Co or Ni (no oxidation necessary); V and Cr yield red colors, and Be gives bluish white. Mo, W, and U give bluish white and light to dark blue shades.

Luster: Subadamantine.

Hardness: 6-7.

Density: 4.25.

Cleavage: Distinct; fracture conchoidal to uneven; extremely brittle.

Optics: $o = 2.61-2.62$; $e = 2.87-2.90$.

Birefringence: 0.287.

Dispersion: 0.28-0.30 (about six times that of diamond).

Pleochroism: None.

Spectral: Absorption band at 4250, cuts off violet end of spectrum.

Luminescence: None; blue stones are slightly electrically conductive.

Comments: The major period of manufacture and marketing of rutile was 1948-1955; this was the first of the long series of diamond imitation gemstones. It is truly a homocreate, but the colors of the manufactured mate-

rial are not duplicated in nature. The softness, extreme brittleness, slightly yellowish cast, and unrealistically high dispersion prevented rutile from achieving the incredible market popularity of later diamond simulants such as cubic zirconia. Rutile has been grown by many techniques, including vapor transport, plasma-arc, Verneuil, hydrothermal, flux, and chemical transport. The majority of commercial crystals were made by Verneuil methods. Asteriated rutile can be made by adding approximately 0.5% Mg oxide and annealing the finished boule in oxygen. Commercial Verneuil production uses a modified flame-fusion torch that allows added oxygen to be supplied to the growing boule, preventing it from becoming oxygen deficient and therefore black. The modified equipment with the added oxygen tube is known as a *tricone torch*.

The color of rutile boules can be improved (that is, made nearly colorless) by adding a small amount of aluminum oxide.

SCHEELITE

Formula: CaWO_4 .

Crystallography: Tetragonal; crystals usually pulled.

Colors: Wide variety with rare earth dopants, including purple; red-brown; pale green; pale yellow; colorless (pure); yellow-brown; dark red; dark yellow-green.

Luster: Vitreous.

Hardness: 4.5-5.

Density: 5.9-6.1.

Cleavage: None.

Optics: $o = 1.920$; $e = 1.937$.

Birefringence: 0.017.

Dispersion: 0.026.

Pleochroism: A purple stone (Nd-doped) had a distinctive spectrum with strong lines at 6670 and 4340 and a distinct band at 5690-5590; other colors also have distinctive absorption spectra.

Luminescence: Pale green = pink in SW; other colors fluoresce mostly shades of blue/blue-white in SW.

Comments: Scheelite is also grown from vapor and flux. Pulled crystals display gas bubbles, occasionally Rh or Ir inclusions (metallic).

SILICON CARBIDE

Formula: SiC .

Crystallography: Hexagonal; crystals platy, thin.

Colors: Green, blue-green, light green, colorless.

Luster: Adamantine.

Hardness: 9.5.

Density: 3.17-3.20.

Cleavage: None.

Optics: $o = 2.65$; $e = 2.69$.
Uniaxial (+).

Birefringence: 0.043.

Dispersion: Approximately 0.09 (about double that of diamond).

Luminescence: Fluoresces mustard-yellow in LW.

Comments: Silicon carbide is an important industrial abrasive material. It is made in large quantities, inexpensively, by fusing sand and coke in an electric furnace. It can also be made in an arc furnace or by flux growth or vapor-phase decomposition. The crystals tend to be platy and well formed, usually very thin, but sometimes thick enough to cut gemstones. The luster, hardness, and dispersion are all excellent for gem use, but the material tends to have a greenish cast. It has never appeared in quantity on the market as a diamond simulant or as a synthetic sold on its own merits.

Inclusions observed include platy, hexagonal-shaped negative crystals, oriented parallel to crystal faces, and scattered small needles.

“SLOCUM STONE”

Formula: A silicate glass with Na, Mg, Al, and Ti.

Crystallography: Amorphous.

Colors: Colorless, white, black, amber, green.

Luster: Vitreous.

Hardness: 5.5-6.5.

Density: 2.41-2.51 (typically 2.48).

Cleavage: None; fracture conchoidal, tough.

Optics: $N = 1.49$ -1.53; kaleidoscopic effect in crossed polars.

Birefringence: None.

Luminescence: Inert in UV.

Comments: This curious opal imitation made by John Slocum of Michigan can be manufactured in sizes up to several centimeters. Magnification reveals thin, irregular splintery inclusions that create a color play. These inclusions are thin pieces of heated and metallicized silica gel. The colors change with the viewing angle.

Bubbles with very unusual shapes are observed in Slocum Stone. The best color play is seen when viewing the included flakes on their large surfaces, rather than edge-on. This material has achieved an amazingly high degree of acceptance and popularity for an imitation material.

SPINEL

Formula: MgAl₂O₄ (+ impurity dopants).

Crystallography: Isometric; crystals are boules made by flame fusion.

Colors: Pure material is colorless. Impurity dopants produce red, brown, green (Cr); blue, green, brown, pink (Fe); yellow, brown, red (Mn); blue (Co); pink (Cu); green (Cr + Mn); blue (Co + Cr); turquoise-blue (Ni). Perhaps as many as 30 distinct colors are produced commercially.

Luster: Vitreous.

Hardness: 7.5-8.

Density: Verneuil = 3.64; Blue Verneuil = 3.63-3.67; Red Verneuil = 3.60-3.66; Red-flux = 3.59+; Blue-flux = 3.63; natural 3.60 (3.59-3.67).

Optics: Verneuil *N* = 2.728; Blue Verneuil *N* = 1.723-1.729; Red Verneuil *N* = 1.720-1.722; Blue-flux *N* = 1.715; natural *N* = 1.718 (1.711-1.719). Synthetic spinel, Verneuil-grown and stabilized with aluminum oxide, typically shows R.I. of 1.728 as compared to the characteristic natural reading of 1.718. However, R.I. and S.G. values for flux-grown stones are within the range of natural spinels.

Cleavage: None; fracture conchoidal.

Dispersion: 0.020.

Pleochroism: None.

Spectral: Typical of dopant. Natural blue spinel characterized by 4600 band due to iron, not seen in (current) synthetics. Stoichiometric red Verneuil spinel has one strong line, not at all like the organ-pipe spectrum seen in natural red spinels.

Luminescence: Pale pink (Mn) and yellow-green stones display strong green fluorescence in UV. Colorless stones fluoresce blue-white in UV. Pale blue stones fluoresce bright orange-red in SW, red in LW. Red stones fluoresce crimson in UV. Pale blue-green stones fluoresce intense yellow in UV.

Inclusions: Growth striae seen in corundum are not typical of Verneuil spinel. Bubbles are also not as diagnostic and may look like negative crystals. Also seen are tiny flat cavities. Flux material is also typically inclusion free. Crystals in natural stones remain a critical diagnostic feature.

Stone Sizes: Verneuil boules typically are about 3-5 inches long and 1-1½ inches in diameter.

Comments: The key diagnostic feature in distinguishing synthetic spinel is the higher R.I. and density produced by the alumina stabilizer in the Verneuil process. Octahedral crystals of red spinel have been grown from the flux.

However, stoichiometric red spinel grown by the Verneuil process may have no excess alumina and therefore display the same physical properties as natural spinel. The color of this material is attributable to traces of Cr and Ti. Faint curved striae and tadpole-shaped bubbles have been observed in the material. Chromium apparently produces a green color when introduced into Verneuil boules grown with excess alumina. If the chemistry is made stoichiometric, the boules crack, but some stones have been cut from this material. Some boules (uncharacteristically) show distinct growth striae and bubbles.

A lapis imitation has been made consisting of a sintered cobalt-rich blue spinel to which is added specks of gold to imitate the pyrite in natural lapis. The material has a strong cobalt absorption spectrum: S.G. = 3.52, hardness = 8, *N* = 1.725.

Asteriated synthetic spinel has also appeared on the market. The stars are, of course, 4-rayed. A weakly chatoyant moonstone simulant has also been reported. The properties given are: *N* = 1.728, S.G. about 3.64; strong greenish fluorescence in SW, no spectrum, weak, irregular star effect; inclusions include air bubbles, some hexagonal. Also strain knots and anomalous birefringence.

STRONTIUM TITANATE

Formula: SrTiO₃.

Crystallography: Isometric; crystals generally manufactured with Verneuil torch.

Colors: Colorless if pure; dopants produce colors as follows:

Dopant	Range of colors (% dopant)		
	0.001	0.02	3
Cr	Yellow-dark brown	dark red-red brown	black
Co	Yellow to yellow-orange	reddish	deep red to blackish red
Fe	Yellow to yellow-brown	brown	dark red-brown to black
Mn	Yellow/yellow-orange		deep red-orange to red to reddish black
Ni	Yellow to orange	reddish orange	deep red to reddish black
V	Yellow to dark red-brown	dark red-brown to black	black
Cb or Ta	Light blue to black or blue-purple		black

Luster: Subadamantine.

Hardness: 5-6.

Density: 5.13.

Cleavage: Indistinct; very brittle.

Optics: $N = 2.40-2.41$.

Birefringence: None.

Dispersion: 0.190 (approximately four times that of diamond).

Luminescence: None.

Comments: This material supplanted rutile in the marketplace. It is nearer to colorless than rutile but is just as soft and brittle and also unrealistically dispersive. Neither rutile nor strontium titanate were truly convincing diamond simulants. Crystals were mass produced by flame fusion, with the usual gas bubble inclusions.

SYNTHETIC TURQUOISE

Formula: Hydrous phosphate of Cu, Al; *totally free of Fe* (versus natural turquoise, which always contains Fe).

Colors: Various shades of blue, intense.

Hardness: 6.

Density: 2.68-2.75.

Cleavage: None; fracture conchoidal; tough.

Optics: $N = 1.59-1.60$; opaque.

Birefringence: None.

Pleochroism: None.

Spectral: No spectrum evident; the spectrum in natural turquoise is mainly due to Fe.

Luminescence: Inert in SW, gray-blue in LW.

Comments: This material was introduced by Pierre Gilson in 1972. It is not an imitation, but a true homocreate with the correct crystalline structure and no apparent binding agent. Most physical properties match those of natural turquoise. The best distinguishing test is the microscopic presence ($50\times$ or more) of a regular, fine-grained texture and a mottled appearance. Also, the material dissolves in HCl. It is sold by weight and it provided in sawn blocks by the manufacturer. It is very compact and tough, takes a high polish, and resembles the finest Persian turquoise in color.

MISCELLANEOUS SYNTHETIC MATERIALS

ALEXANDRIUM

Li Al Silicate (+ Nd). Amorphous (glass). Light blue to lavender. Hardness = 6.5. $N = 1.58$. Heat sensitive.

"BANANAS"

$Ba_2NaNb_5O_{15}$. Colorless (slightly yellowish). $N = 2.31$. Dispersive.

BARIUM TITANATE

$BaTiO_3$. Isotropic. Hardness = 6-6.5. S.G. = 5.90. $N = 2.40$.

BERYL

Be Al silicate, colored by Co, grown hydrothermally; (also blue beryl, dark color = Fe, light blue color = Co). Pleochroic: $o =$ light brown; $c =$ reddish-purple. Strong absorption lines at 5860, 5670, and 5430.

BISMUTH GERMANIUM OXIDE

$Bi_{12}GeO_{20}$ or $Bi_4Ge_3O_{12}$. Isotropic. Bright golden orange. Hardness = 4.5. $N = 2.07$. S.G. = 7.12.

BROMELLITE

BeO. Colorless. Hardness = 8-9. S.G. = 3.0-3.02. R.I. = 1.720-1.735. Birefringence = 0.015. Fluoresces faint orange in LW.

CALCIUM TITANATE (PEROVSKITE)

$CaTiO_3$. Orthorhombic. Hardness = 5-6. S.G. = 4.05. R.I. (mean) = 2.40.

CALCIUM FLUORIDE (FLUORITE)

CaF_2 (doped with rare earths). Isometric. Wide range of colors. Hardness = 4.

Colorless: R.I. = 1.44; S.G. = 3.20; no absorption spectrum; fluoresces green in LW.

Green: R.I. = 1.43-1.45; S.G. = 3.19-3.21; spectrum shows band in deep red, fine bands at 6900, 5300, and 4900; may fluoresce blue.

Red (doped with U): R.I. = 1.44; S.G. = 3.18; RE spectrum, many lines in yellow-green, sharp line at 3650; inert in UV.

CADMIUM SULFIDE (GREENOCKITE)

CdS. Hexagonal. Hardness = 3-4. S.G. = 4.7-4.9. R.I. = 2.50-2.52. Inert in SW, faint orange in LW.

HEMETINE

Fe oxides + Pb oxide. Sintered product designed to imitate hematite. S.G. = 7. Streak black to reddish black. Magnetic; natural hematite is not.

LASERBLUE

Borosilicate + Cu. Amorphous (glass). Medium to dark blue, very intense. Hardness = 6.5. $N = 1.52$. Heat sensitive, difficult to cut.

LITHIUM TANTALATE

$LiTaO_3$. Trigonal. Colorless. Piezoelectric. Hardness = 5.5-6. R.I.: $o = 2.175$; $e = 2.18-2.22$. Birefringence =

0.006. S.G. = 7.3-7.5. Dispersion = 0.087 (about twice that of diamond).

LITHIUM NIOBATE (LINOATE)

LiNbO_3 . Trigonal. Colorless, violet, green, red, blue, yellow. Dichroic. Hardness = 5+. R.I.: $o = 2.21$; $e = 2.30$. Birefringence = 0.090. S.G. = 4.64-4.66. Dispersion = 0.130 (about three times that of diamond). Inert in UV.

LITHIUM FLUORIDE (+Cr)

LiF (+Cr). Hardness = 3-4. S.G. = 2.64. $N = 1.392$. Isotropic.

MAGNESIUM OXIDE (PERICLASE)

MgO . Isometric. Colorless. S.G. = 3.55-3.60. $N = 1.734$ -1.738. Cleavage = cubic. Hardness = 5-6. May be colored (blue/dark blue/green) also by irradiation. Green: $N = 1.738$; S.G. = 3.75.

MAGNESIUM SILICATE (FORSTERITE)

Mg_2SiO_4 . Colorless crystals grown by pulling, doped with Ni = green, with V = blue.

POWELLITE

CaMoO_4 . Tetragonal. Colorless (pulled crystals). Ho-doped: S.G. = 4.34; R.I. = 1.924-1.984.

PHENAKITE

Be_2SiO_4 . Hexagonal. Colorless; may be turned yellow by irradiation. Hardness = 7.5. Blue-green (V-doped): S.G. = 3.0; R.I. = 1.654-1.670.

TIN OXIDE (CASSITERITE)

SnO_2 . Tetragonal. Colorless to slightly yellowish. R.I. = 1.997-2.093. Birefringence = 0.098. Dispersion = 0.071 (about $1\frac{1}{2}$ times that of diamond). S.G. = 6.8-7.1. Hardness = 6-7.

VICTORIA STONE (= Iimori Stone)

A complex silicate glass, apparently with an amphibole structure; highly chatoyant, due to network of fibers. Made by melting various minerals. Made in wide color range.

Nephritelike: R.I. = 1.61; S.G. = 3.00; hardness = 6.

Jaditelike: R.I. = 1.50; S.G. = 2.80; hardness = 6.

YTTRIUM ALUMINATE

YAlO_3 . Isometric. Colorless, doped with rare earths to give many colors, including green, red, bluish, orangy pink, pink, blue-violet. $N = 1.94$ -1.97. S.G. = 5.35. Hardness = 8.5. Dispersion = 0.033. (just below diamond). Shows rare earth spectrum; a good diamond simulant.

YTTRALOX

Y_2O_3 or $(\text{Y,Th})_2\text{O}_3$. Isometric. Colorless (turns yellowish if impure). R.I. = 1.92. S.G. = 4.84. Hardness = 6.5-8. Dispersion = 0.050 (just above diamond). A reasonable diamond simulant; the Th-doped material is a sintered polycrystalline product, with about 10% Th oxide, and slightly lower dispersion (0.039).

ZINC ALUMINATE (GAHNITE)

ZnAl_2O_4 . Isometric; a spinel mineral. $N = 1.805$. S.G. = 4.40. Hardness = 7.5-8.

ZINC SULFIDE (SPHALERITE, WURTZITE)

ZnS . Sphalerite: isometric; $N = 2.30$; S.G. = 4.06; hardness = 3.5-4.

Wurtzite: hexagonal; R.I.: $o = 2.356$; $e = 2.378$; birefringence = 0.022; S.G. = 4.03; hardness = 3.5-4.

ZINC OXIDE (ZINCITE)

ZnO . R.I. = 2.01-2.03. Hexagonal. Hardness = 4.5. S.G. = 5.43-5.70.

Homocreate Materials That Have Been Synthesized

ANDRADITE	GROSSULAR	RUTILE
APATITE	HALITE	SANMARTINITE
AZURITE	HEMATITE	SCAPOLITE
BADDELEYITE	IOLITE	SCHEELITE
BERLINITE	JADEITE	SODALITE
BERYL	KYANITE	SPHALERITE
BROMELLITE	LAZURITE	SPINEL
CALCITE	LEUCITE	SPODUMENE
CASSITERITE	MAGNETITE	TAAFFEITE
CERARGYRITE	MALACHITE	TOPAZ
CHRYSOBERYL	MIMETITE	TOURMALINE
CINNABAR	NANTOCKITE	UVAROVITE
CORUNDUM	OLIVINE	VANADINITE
CUPRITE	OPAL	VARISCITE
DIAMOND	PERICLASE	VILLIAUMITE
FLUORITE	PEROVSKITE	VIVIANITE
FORSTERITE	PHENAKITE	WULFENITE
GADOLINITE	POWELLITE	WURTZITE
GAHNITE	PROUSTITE	ZINCITE
GREENOCKITE	QUARTZ	ZIRCON

Trade Names of Synthetics

ALEXANDRITE

Alexandria-Created Alexandrite (Creative Crystals)
Crescent Vert Alexandrite (Kyocera)
Inamori Created Alexandrite (Kyocera)

COLORLESS SAPPHIRE

Brillite
Diamondette
Diamonflame
Emperor-lite
Gemette
Jourado Diamond
Ledo Frozen Fire
Mr. Diamond
Thrilliant
Vega Gem
Vesta Gem
Zircolite

CORUNDUM

Amaryl (pale green)
Crown Jewels (colorless)
Danburite (pink)
Diamondite (colorless)
Gemini Ruby
Gemini Sapphire
Syntholite (red-violet)
Ultralite (red-violet)
Violite (red-violet)
Walderite (colorless)
Zirctone (blue-green)

CUBIC ZIRCONIA

Cerene
C-Ox

Cubic-Z

Cubic Zirconia
Cubic Zirconia II
Cubic Zirconium
Cubic Zirconium Oxide

CZ

Diamonair II
Diamondite
Diamond-QU
Diamonesque
Diamonique III
Diamonite
Diamon-Z

Diconia
Djevalite
Fianite
Phianite
Phyanite
Shelby
Singh Kohinoor
Zirconia
Zirconium
Zirconium Yttrium Oxide

EMERALD

Chatham Created Emerald
Crescent Vert Emerald (Kyocera)
Gemerald
Gilson Created Emerald
Emerita (Lechleitner overgrowth)
Igemerald (I.G. Farben)
Inamori Created Emerald (Kyocera)
Linde Created Emerald
Lenix Emerald (Lenic Co.)
Regency Created Emerald (Vacuum Ventures)
Symerald (Lechleitner overgrowth)

GGG

Diamonique II
Galliant
Triple-G

RUTILE

Astryl
Brilliante
Capra; Capri
Diamothyst
Gava Gem
Jarra Gem
Java Gem
Johannes Gem
Kenya Gem
Kima Gem
Kimberlite Gem
Lusterlite
Meredith
Miridis
Rainbow Diamond
Rainbow Gem
Rainbow Magic Diamond
Rutania
Rutile
Sapphirized Titania
Sierra Gem
Tania-59
Tirium Gem
Titangem
Titania
Titania Brillante
Titania Midnight Stone
Titanium
Titanium Rutile
Titan Stone
Ultimate
Zaba Gem

SPINEL

Alumag
Aquagem (pale blue)
Berylite (pink)
Brazilian Emerald (yellow-green)
Corundolite
Degussite (blue-lapis imitation)
Dirigem (yellow-green)
Emerada (yellow-green)
Erinide (yellow-green)
Jourado Diamond (colorless)
Lustergem

Magalux
Perigem (yellow-green)
Radiant
Rozircon (pink)
Strongite
Wesselton Simulated Diamond (colorless)

YAG

Alexite
Amatite
Astrilite
Circolite
Dia-Bud
Diamite
Diamogem
Diamonair
Diamondite
Diamone
Diamonique
Diamonite
Diamonte
Di 'Yag
Geminair
Gemonair
Kimberly
Linde Simulated Diamond
Nier-Gem
Regalair
Replique
Somerset
Triamond
YAG
YAIG
Yttrium Aluminum Garnet
Yttrium Garnet
Yttrogarnet

STRONTIUM TITANATE

Bal de Feu
Brilliante
Continental Jewel
Counterfeit Diamond
Diagem
Diamontina
Dynagem
Fabulite
Jewelite
Kenneth Lane Jewel
Lustigem
Marvelite
Pauline Trigere

Rossini Jewel
 Sorella
 Starilian
 Strontium Mesotitanate
 Strontium Titanate
 Symant
 Wellington Jewel
 Zeathite
 Zenithite

MISCELLANEOUS

NAME	COMPOUND
EMERALDINE	Stained Chalcedony
LAVERNITE	Periclase
ROYALITE	Glass
SIERRA GEM	Rutile coated with sapphire
STAR TANIA	Star rutile
TRIPLITINE	Emerald-coated beryl triplet