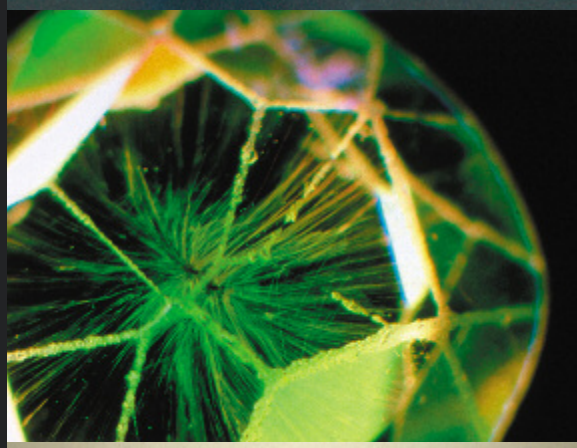
GIA®

Colored Stones

BOOK 1



1. Introduction
2. Gemstone Formation and Mining
3. Gems and Their Physical Properties
4. Gems and Light
5. Synthetics and Imitations
6. Treatments

9/2018

Colored Stones
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Welcome to the *Colored Stones* course! When you've successfully completed the course:

- You'll have a solid foundation of colored stone knowledge.
- You'll be able to apply the basic principles of gemology to judge the color, clarity, and cut of colored gemstones.
- You'll be familiar with most major gem treatments.
- You'll understand the structure of the colored stone industry, from mining through production and marketing, up to final retail sales.
- You'll qualify for positions such as gem laboratory staff, sales associate, assistant buyer, and customer service representative.

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Introduction

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Welcome to *Colored Stones* Assignment 1. With the knowledge you gain from this assignment, you'll be able to:

- Understand the basics of gem chemistry and physical structure.
- Describe the difference between organic and inorganic gems.
- Explain how gemologists classify gems.
- Understand how a gem's availability affects the way it's marketed.
- Understand the importance of honestly disclosing gem treatments.

Courtesy China Gems Magazine and Enzo

The colored stone market has changed dramatically in the last couple decades, with big changes in consumer demand as well as in gem resources.

Introduction

Colored stones have a special allure. For centuries, they've been treasured by maharajahs, emperors, and kings. They're mined in the mountains, jungles, and deserts of the world, far from the modern world of most jewelry consumers. Locations are often remote, so access can be challenging.

Source—A gem-producing locality.

Source countries sometimes have complicated laws regarding the mining and marketing of gems. A gem's supply might change from a torrent to a trickle overnight if a country's government changes its regulations and export procedures. Such changes can have dramatic effects on a gem's price, availability, and popularity.

Although the Big 3—ruby, sapphire, and emerald—have the strongest hold on consumer awareness, other enticing gems also compete for attention in today's marketplace. Some, like tanzanite and tsavorite, were unknown until fairly recently. Others, like spessartine garnet and cultured freshwater pearl, weren't widely available until new sources appeared.

August Theodor Schoefft/Christie's Images Inc.

Gems have been coveted by royalty throughout history. An Indian maharajah displays his priceless treasure of rubies, emeralds, and pearls.

The study of colored stones is not just about gemology. The economics of supply and demand are just as important. Today—more than at any time in the past—the number of new gems and new gem sources makes it necessary for the people who work with colored stones to be better informed.

This course blends the science of gemology with current product knowledge and practical trade examples to give you the information you need for a successful career in the jewelry industry.

Robert Weldon/GIA, courtesy Betty Sue King, King's Ransom

New sources can increase a gem's availability and enhance its position in the colored stone market. The past ten years have seen big increases in the quantity and quality of Chinese freshwater cultured pearls.

Robert Weldon/GIA, courtesy Meg Berry

The discovery of new spessartine garnet sources in East Africa added to the gem's availability.

Brendan Laurs/GIA

The miner is often the first to recognize a colored stone's value. Like many colored stones, this tourmaline comes from an exotic location and was extracted using primitive mining methods.

This course will serve as a guide to the multitude of colored stones in today's market. You'll learn how wholesalers, gem cutters, and miners judge and market them. You'll discover which gems are most commercially important and why. You'll understand the value differences among gems. You'll gain insight into the shifting patterns of colored stone supply and how they affect gem prices and availability.

Whether you work in retail or in the wholesale colored stone industry, this course will give you the information you need to sell more colored stones.

Ralph Gabriner/Maija Neimanis

This contemporary necklace features a combination of organic and inorganic gems. The pearls were produced by a living animal—a mollusk—while the aquamarines and peridots were derived from non-living matter.

What is a Gem?

- What are gems made of?
- What is a mineral?
- How do gemologists classify gems?

Inorganic—Composed of, or arising from, non-living matter.

Organic—Produced by, or derived from, a living organism.

Natural gems—Gems produced by natural processes, without human help.

Almost all the colored stones you'll encounter in this course form in the earth. They're *inorganic*, which means that they're composed of— or arise from—non-living matter. Some other gems—like pearl, coral, amber, and ivory—are produced by living organisms, which means that they're *organic*.

Whether gems form within the earth or from animals or plants, they're referred to as *natural gems*. This distinguishes them from materials produced in a factory or laboratory.

Atoms and Crystals

All gems—inorganic and organic—are made up of *atoms*. Atoms are the basic structural units of matter and the smallest units that retain the characteristics of a *chemical element*. Chemical elements consist of only one kind of atom, and combinations of them make up and color gems. Chromium atoms, for example, color ruby red, and aluminum and oxygen atoms build its crystals.

The kinds and relative quantities of atoms that make up a material comprise its *chemical composition*. Each gem has its own unique chemical composition. Emerald, for example, is a precise combination of beryllium, silicon, aluminum, and oxygen atoms.

Knowing about the atoms and their arrangement within a gem will help you understand its physical properties, right down to the sharpness of its *facets* and the perfection of its polish. The types of atoms a gem contains and how they're combined determine everything you see when you look at a gem and how it feels when you handle it.

Atom—The basic structural unit of all matter.

Chemical element—A substance that consists of atoms of only one kind.

Chemical composition—Kinds and relative quantities of atoms that make up a material.

Facet—A flat, polished surface on a finished gem.

Jeffrey Scovil, courtesy Shades of the Earth

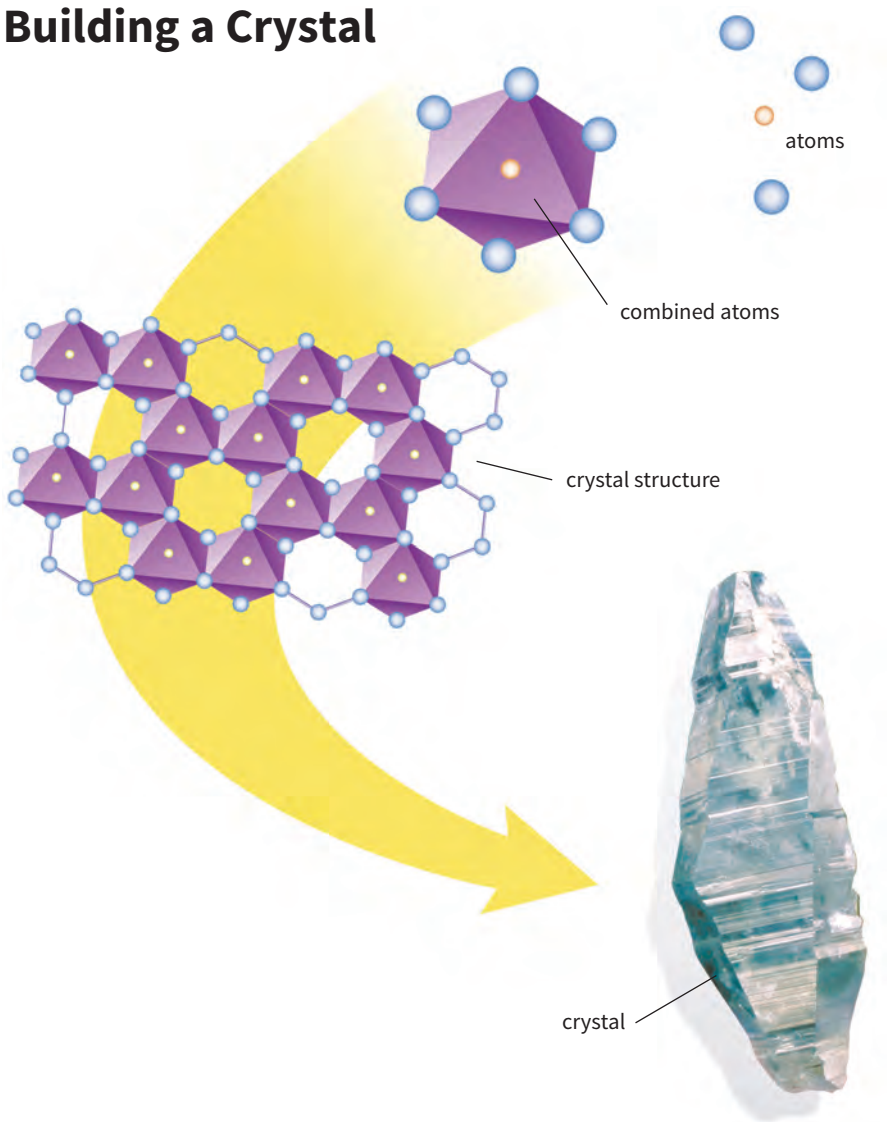
Each gem is built from a specific combination of atoms of different types and amounts. This combination is called chemical composition.

KEY CONCEPTS

Most gems are minerals.

To be a gem, a mineral must be beautiful, durable, and rare.

Building a Crystal



Peter Johnston/GIA, crystal courtesy Jack Halpern Collection

Atoms are the basic building blocks of all matter, including crystals. Different kinds of atoms combine in different ways to form gems of all kinds.

Mineral—A natural, inorganic substance with a characteristic chemical composition and usually characteristic structure.

Rock—A natural material composed of masses of mineral crystals of one or more kinds.

Almost all the gems used in jewelry are *minerals*. Minerals are natural, inorganic substances with characteristic chemical composition and—usually—characteristic structure, too. Synthetic gem materials aren't minerals because they're grown in a laboratory rather than in the earth.

While most gems are minerals, very few minerals qualify as gems. To be a gem, a mineral must be beautiful, durable, and rare. These three factors are what make a gem desirable. Of the more than 3,000 minerals discovered so far, only about 100 qualify as gems.

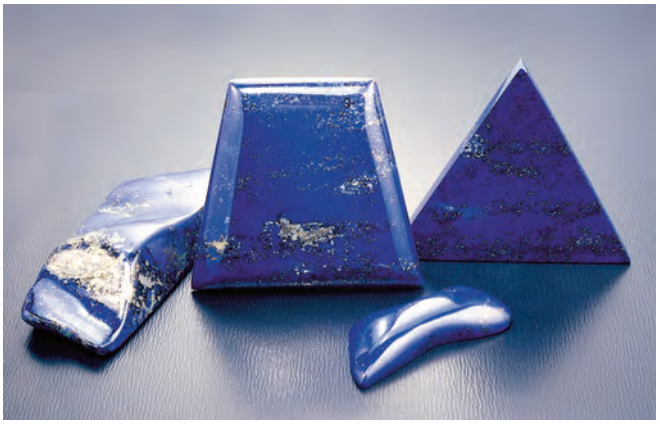
Some gems are *rocks*, which means they're made up of masses of mineral crystals. Some rocks, like marble, are composed of crystals of a single mineral, but most contain more than one kind. An example is lapis lazuli, which is made up of the minerals lazulite, calcite, and pyrite.

Robert Weldon/GIA, courtesy Mr. Davenport

Chromium is the chemical element that gives these rubies their vibrant red hue.

Jeffrey Scovil, courtesy Bob Johnson Collection

Most minerals lack the beauty, durability, and rarity to be gems. Out of the 3,000 minerals on earth, only about 100 qualify as gems. Emerald is one of them.



Robert Weldon/GIA, courtesy Gary Bowersox

The mottled gray patches and brassy specks in these lapis lazuli specimens are the minerals calcite and pyrite. Lapis lazuli is classified as a rock because it consists of more than one mineral.

Robert Weldon/GIA, courtesy Richard T. Liddicoat

Many gemstones are silicates, which means they contain a combination of silicon and oxygen. Quartz is one of the simplest silicates because it's composed almost entirely of those two elements.

Silicate—A mineral that contains the elements silicon and oxygen.

Crystal structure—Regular, repeating arrangement of atoms in a material.

Many of the most common minerals—the main components of the rocks near the earth's surface—are *silicates*, which simply means they contain the elements silicon and oxygen. Most quartz gems are composed almost solely of silicon and oxygen. That's why the term silica is sometimes used to describe quartz. The list of gems that are silicates also includes beryl, garnet, tourmaline, jadeite, spodumene, and opal.

Minerals almost always form as crystals. A crystal is solid matter with atoms arranged in a regular, repeating, three-dimensional pattern called *crystal structure*, or crystal lattice. A crystal can be natural or manmade.

Most transparent gems are cut from one large crystal. Other gems— like turquoise—are made up of many tiny crystals that might not be visible to the unaided eye. Still others, like lapis lazuli, are made up of mixtures of different mineral crystals.

Many rocks are intergrowths of clearly visible mineral crystals. Architects choose granite for the facades of many buildings because of the decorative effect of its differently colored, interlocking crystals.

While the majority of colored stones are crystals, there are some important exceptions. Fire opal appears to have the same transparency as many other gems, but it lacks a regular, repeating crystal structure. Gemologists describe gems without a regular crystal structure as *amorphous*. Amber is another amorphous gem material.

Amorphous—Lacking a regular crystal structure.

Jeffrey Scovil, courtesy Wayne Thompson Collection

The pattern of a gem's atoms is called its crystal structure. This tourmaline crystal's orderly internal structure is reflected externally in its symmetrical shape.

Robert Weldon/GIA

Robert Weldon/GIA, courtesy Martha Zuniga

Amorphous gems, like opal (top) and amber (bottom), lack the orderly crystal structure that's found in gems like ruby and emerald.

Gem species—A broad gem category based on chemical composition and crystal structure.

Species, Varieties, and Mineral Groups

Gemologists divide natural gem minerals into gem species. A *gem species* is a broad gem category based on chemical composition and crystal structure.

The mineral species beryl, for example, is made up of a regular, repeating structure of beryllium, aluminum, oxygen, and silicon atoms. Those atoms—in the proper arrangement and relative quantities—always define that mineral species. But the broad species name isn't enough to describe

Shane McClure/GIA, courtesy David Humphrey and N.D. International, Evan Caplan & Co.

Gemologists classify gems into broad categories called species. This suite of rough and cut gems from Sri Lanka includes the gem species spinel, zircon, chrysoberyl, and corundum. Each one has its own chemical composition and crystal structure.

the wealth of color—glorious greens, blues, pinks, reds, and yellows—of a gem species like beryl.

Gemologists use the term *variety* to describe these color variations. Variety is a subcategory of species, based on color, transparency, or *phenomenon* (a phenomenon is a special optical effect, like the star in star sapphire, or the blue sheen in moonstone). In the beryl species, for example, aquamarine is the most widely known blue variety, and emerald is the highly prized green variety.

Gem variety—A subcategory of species, based on color, transparency, or phenomenon.

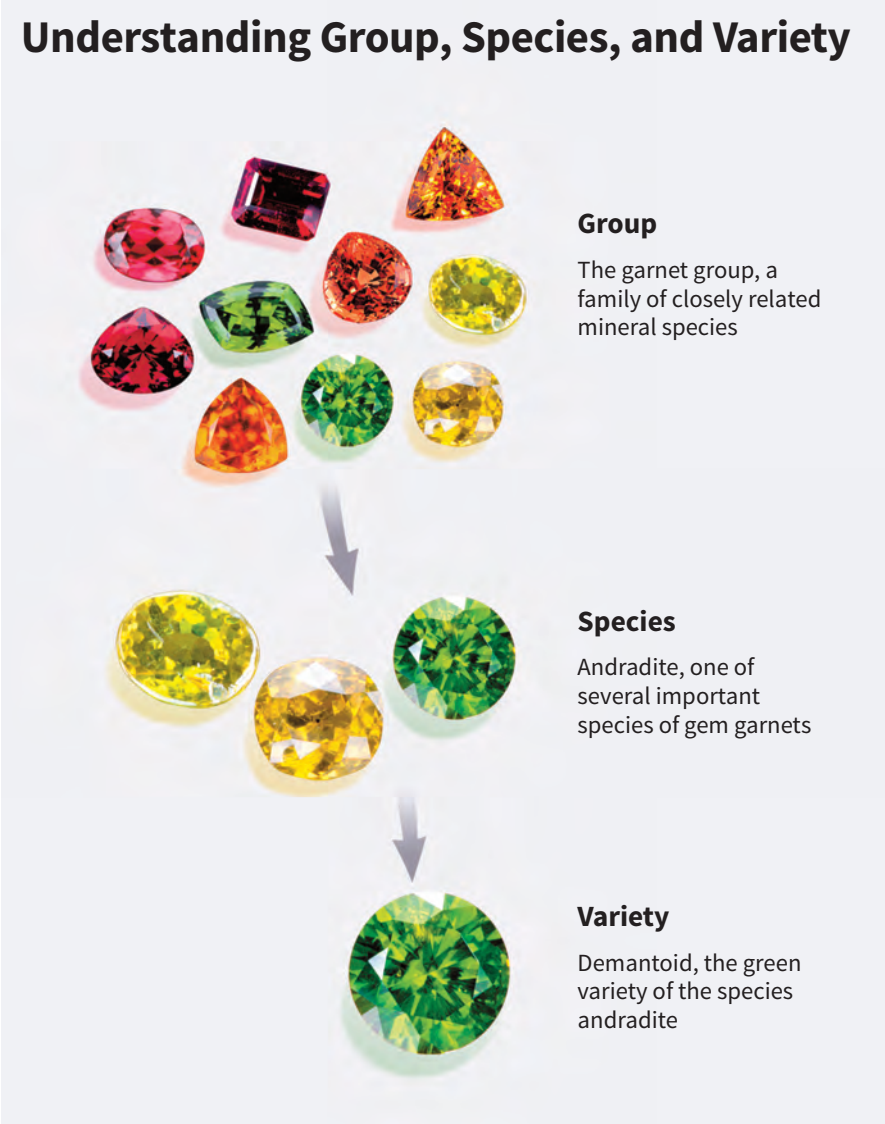
Phenomenon—An unusual optical effect displayed by a gem.

Kevin Schumacher/GIA, courtesy Betteridge

Peridot is a species with a narrow yellowish green to greenish yellow color range, so it has no color-based varieties.

Tino Hammid/GIA

Zircon is a gem species with many color varieties. A zircon is classified by its color and species name—blue zircon, green zircon, etc.



Peter Johnston/GIA

The garnet group is a family of gems with the same crystal structure and the same basic chemistry of aluminum, silicon, and oxygen. Their differences lie in the other chemical elements they contain, which give them differing colors and properties.

Group—A family of gems from several closely related mineral species.

Sometimes, several gem species differ only slightly from each other. Because they're so similar, gemologists might classify them as a *group*. A group is a family of closely related mineral species that share the same crystal structure and basic chemistry, but differ slightly in other details. These differences often lead to differences in physical and optical properties. There are many mineral groups, but only a few contain important gem species. The best-known gem groups are garnet, feldspar, and tourmaline.

The important species in the garnet group—almandine, pyrope, spessartine, grossular, and andradite—share the same crystal structure and basic chemistry, but they have slight differences in chemical composition. For

Valerie Power/GIA

Quartz is relatively common, and prices for large specimens sold at gem shows are often very reasonable.

Robert Weldon/GIA

The stones in the garnet group come in a range of dramatically different colors.

Robert Weldon/GIA, courtesy Paula Crevoshay

Although quartz is common and some varieties are very inexpensive, this one's cross-shaped inclusions make it both rare and valuable. The designer setting adds even more to its value.

example, almandine is rich in iron, while pyrope contains significant amounts of magnesium. You'll learn more about this in Assignment 24.

A gem's rarity can be an important part of its value, and that rarity is very closely related to the way it forms within the earth. For example, the formation conditions that produce red garnets are far more common than those that produce ruby. Another factor is that some gems contain more widely available elements than others, so they're more prevalent. You'll learn more about how gems form in Assignment 2.

A gem's rarity and beauty affect how it's marketed. These factors also affect its value. They are just as important to understand as things like crystal structure and chemical composition.

The Colored Stone Market

- How are mining and marketing different for diamonds and colored stones?
- How does the supply of a gem affect its marketability?
- How do treatments impact the sales of certain colored stones?

There's a greater selection of colored stones available today than ever before. And new cutting techniques present familiar materials in interesting ways. Because there's more choice, jewelry designers have to catch customers' eyes with distinctive products and designs.

Ralph Gabriner, courtesy Jane Bohan Inc.

New sources often introduce new gem materials that can be combined in interesting ways. A designer combined rose-colored cultured pearls and a rose-cut pink tourmaline with 18K gold to create this elegant jewelry suite.

John Parrish/Richard Krementz Gemstones

Colored stones are more popular today than ever before. Gems like garnet, rubellite, and tanzanite can act as attention-getting center stones in contemporary rings.

John Parrish/AGTA, courtesy Kaiser Gems; F. Joseph Kremer, Goldsmith Inc.

Gems like citrine, peridot, and moonstone can be combined into colorful bracelets and other jewelry pieces.

A fine ruby can provide the warmth that a diamond's icy beauty can't match. Even so, diamonds are economically more important than colored stones.

The US is the world's largest gem-consuming market, followed by China. In 2016, US retail sales of diamond jewelry amounted to about $37 billion. By comparison, US sales of colored stone jewelry were about $6.4 billion—just a fraction of the diamond total. Sales of emerald, ruby, and sapphire jewelry made up the majority of the latter figure.

Promotion of diamonds changed when De Beers moved to a supplier-of-choice business model. This delegated diamond promotion to more players and converted a single-channel system to a multichannel system. However, because De Beers had spent many millions of dollars on global diamond advertising for decades before that, their efforts still play an important role in consumer demand. There is no single marketing source for colored stones, making the colored stone market far more diverse and fragmented.

Courtesy Diamond Promotion Service

For decades, diamond owed its enormous popularity in part to De Beers' widespread and well-organized promotional efforts. The marketing of colored stones has always been inconsistent and underfunded.

Courtesy Tiffany & Co.

Diamonds are an extremely important part of the jewelry industry. Even colored stone jewelry is often accented with diamonds.

Diamonds are also featured in many more types of jewelry. Even if a fine sapphire or emerald forms the centerpiece of a ring, it's almost always surrounded by an array of diamonds.

Multinational mining companies invest hundreds of millions of dollars and take many years to develop diamond mines, but the potential profits are enormous. The developers of Canada's Ekati mine spent more than $700 million for development and early operation, but the estimated value of the diamonds in the ground is more than $8.6 billion.

Many diamond deposits are vast enough to sustain mining for decades. For example, the Jwaneng mine in Botswana is essentially a gigantic pit, 2 km (1.24 mi.) long, 1 km (0.62 mi.) wide, and 200 m (650 ft.) deep. But it's the world's most profitable diamond mine, with more diamonds per ton of ore than any other mine in Africa.

Because of the size of their potential output, most diamond mines are massive industrial operations. Mining of this size and scope is almost unknown with colored stones. Most colored-stone mining operations are small in scale, worked by individual miners who are working to feed their families and hoping for a chance at a better life.

Also, unlike diamond mines, colored stone deposits can be mined sporadically for centuries or exploited to exhaustion in just a few decades. You'll learn more about colored stone mining in the next assignment.

KEY CONCEPTS

Many colored stones are mined by independent miners using small-scale mining methods.

Robert Weldon/GIA

The enormous scale of Botswana's Jwaneng diamond mine would overpower the scope of most colored stone operations.

Robert Weldon/GIA

Diamond mining companies invest billions of dollars in elaborate mechanized systems and heavy equipment.

Andrew Lucas/GIA

Individual miners, like this one in Cambodia, recover a significant percentage of colored gemstones by patiently sifting through gravel.

Rakotosaona Nirina

Most colored stone mines, like these in Madagascar, are primitive.

While approximately 80 percent of colored stones are mined by independent and small-scale mining operations, the last couple of decades have seen more investment by large multinational companies, including publicly traded companies. This has created larger and more sophisticated mining operations as well as more consistent supplies of some stones. For example, a much higher percentage of the world's emerald supply now comes from large mining operations.

As the global consumer market becomes more and more concerned with transparency, sustainability, and corporate responsibility, the challenges of establishing an ethical supply chain are greater for the colored stone industry than for the diamond industry. One of the greatest challenges is

Eric Welch/GIA, courtesy Hutang Gems & Jewelry Ltd.

Chrome diopside is heavily promoted on television in the US and through jewelers in China. The newly developed consumer demand resulted in large quantities of this green gem being sorted and cut in China.

Courtesy Bellini & Co.

Today, designers create contemporary jewelry that features the most popular colored stones.

to protect both the investment of large corporations and the rights of independent miners, many of whom are unlicensed and operate outside formal channels.

Even though they're not as economically important as diamonds, colored stones generate many billions of dollars worldwide, not only for the nations that mine and process rough gems, but also the manufacturers, wholesalers, and retailers who turn them into jewelry products and sell them to consumers.

Some of the best-selling and most well-known colored stones are blue sapphire, tanzanite, ruby, emerald, cultured pearl, tourmaline, opal, amethyst, and red garnet. These gems are more familiar to most consumers than others like zircon and tsavorite garnet. The difference is due to a combination of factors. One is their availability, in terms of quantities produced. Another factor is their marketability, which often affects, and relies on, consumer preferences. The third factor has to do with treatments and their ethical *disclosure*, which requires clearly informing consumers about the nature of the gems they're buying.

Disclosure—Clearly and accurately informing customers about the nature of the goods they buy.

Technology and consumer sources of colored stones have played major roles in altering awareness and increasing sales of many colored stone types. Television shopping has even created markets for some stones that were once rarely used in jewelry, like scapolite and sphene. The ability to reach more than a hundred million households has helped a stone like chrome diopside become a strong seller, even though it had very little public recognition before newly developed consistent supplies appeared. New markets with strong purchasing ability and consumer markets open to new sources like China have also hugely affected the market.

Production and Availability

As you've seen, most colored stone mines are small-scale operations in remote areas, often operated using primitive technology and tools. Communications and infrastructure might be poor. In addition, many mining areas have difficult climates and a prevalence of malaria and other diseases. These deposits are generally worked feverishly for short periods of time and then abandoned when they become less profitable or more challenging to mine.

Vincent Pardieu/GIA

Colored stone yields can fluctuate along with the levels of production from small-scale miners.

Andrew Lucas/GIA

Sri Lanka is a major global sapphire trading center. Street vendors offer Sri Lankan sapphires along with production from Africa. An increase in Madagascar mining production is almost immediately noticed in Sri Lankan markets.

Vincent Pardieu/GIA

New sources, like this sapphire mine in Ilakaka, Madagascar, contribute to rising gem supplies worldwide. Rising and falling supplies affect the gem market in many ways and at many levels.

These mining practices lead to temporary abundance of a particular gem, followed by a shortage. This fluctuation in supply usually produces wild price swings that make a gem difficult to market.

Politics and changes of government in producer countries can have a drastic effect on gem production. For centuries, the Mogok region of Myanmar (formerly Burma) was the world's most important source of fine rubies—known as "Burmese" rubies—that commanded high prices in upscale jewelry salons and auctions. In the 1960s, a military coup in Myanmar caused this supply to shut down.

Michel Viard/AFP

Michel Viard/AFP

Thailand's corundum mines were mostly exhausted by the 1990s, but the country remained a premier corundum cutting and manufacturing center. In Bangkok, workers fashion sapphires (left) and other gems, then set the stones in jewelry (above).

Neighboring Thailand also had ruby mines, but the market generally preferred the bright Burmese rubies to darker Thai rubies. Rapid advances in heat treatment made Thai ruby attractive, and suddenly Thailand's ample supplies of smaller, less expensive rubies were just what the market needed. Thai ruby supported the industry's needs for more than two decades, but by the late 1980s, even those supplies began to run out.

In the meantime, miners found a rich new ruby deposit in Myanmar. This deposit became the most important source of ruby during the 1990s. In the space of thirty years, the world's premier ruby supplier had switched from Myanmar to Thailand and back to Myanmar again.

The Burmese rubies of the 1960s were notably more intense than the darker, redder ones from Thailand that became so commercially important in the 1970s and 1980s. When Thai ruby ran out in the early 1990s, dealers had to change back to Burmese rubies—this time from a different source in Myanmar—with subtle differences of their own.

By 2015 a relatively new discovery in Mozambique became the world's leading ruby supplier. A large publicly traded company brought their mining expertise and set up an auction system similar to one they had used for selling Zambian emerald rough. Their large-scale, sophisticated mining operation and controlled supply system exist alongside independent miners working small pits by hand with simple tools.

Vincent Pardieu/GIA, courtesy Gemfields

Mozambique rubies are mined by large, publicly traded companies that bring in expertise and heavy equipment.

Andrew Lucas/GIA

In Mozambique, ruby is also mined by independent miners using hand tools in small pits.

Each time the source changed, colored stone wholesalers and dealers had to educate their customers to accept changes in ruby price, general appearance, and quality. Because the jewelry industry clings to tradition and doesn't accept change very readily, it takes time for wholesalers to get jewelry manufacturers and retailers to accept stones of noticeably different appearance than the ones they're used to. This is just one example of how changes in supply can affect the colored stone market. Consumer demand is another factor.

KEY CONCEPTS

An appealing name can make a gem much easier to sell.

Consumer Preferences and Marketing

As you will learn, ruby, sapphire, and emerald have romantic histories that link them to the rich and famous. But other, lesser-known gems might also attract consumers' imaginations from time to time.

Gem colors pass in and out of fashion just like clothing colors do. Warm earth colors, russet browns, and peach shades, in gems like citrine and zircon, might be in favor temporarily to complement a season's fashions. Delicate pastel shades of peridot, aquamarine, and pink tourmaline might be one year's favorites, only to be replaced by stronger, bolder primary colors the following year.

Sometimes, clever marketing can greatly boost a gem's popularity. For this to succeed, the gem must be available in sufficient quantity to market, and it must be sufficiently attractive—or have some special quality—that consumers will find desirable. It must also have a name that's marketable and easy for consumers to remember, or its name must be already well established, like ruby and sapphire.

The history of tanzanite can help you understand the relationship between supply, demand, and marketing. The gem is an attractive blue variety of zoisite that's mined in the African country of Tanzania.

Robert Weldon/GIA, courtesy Beacab Gems

Consumer demand for both ruby and emerald has grown steadily for ages. This 18K gold ballerina brooch is set with rubies, emeralds, and diamonds.

Robert Weldon/GIA, courtesy Campbell Bridges and Bridges Exploration Co., Nairobi, Kenya

Many consumers are not as familiar with the colored stones in this assortment from East Africa as they are with the Big 3. The colors of some of these stones pass in and out of popularity along with fashion trends.

Courtesy Tiffany & Co.

In the 1960s, Tiffany & Co. created a marketing campaign for tanzanite that inspired intense demand for the newly discovered gem.

An upscale jeweler invented the name tanzanite in the 1960s to market the gem as an alternative to fine sapphire. The association with the famous jeweler added status to the gem's highly marketable name.

Unfortunately, tanzanite had only a single source, so its supply was easily upset by external events. In the 1970s, the Tanzanian government took over the mines, and supplies declined considerably.

At first, because demand for the gem was still strong, prices rose as wholesalers competed for the diminishing supply. Less tanzanite reached the consumer, and retail prices increased sharply. When prices reached a certain level, consumers resisted paying the price, and promotion of the gem stopped. Tanzanite slipped from public awareness and became a gem sought by only a privileged few.

In the 1980s, the Tanzanian government lost control of the tanzanite mining area, and thousands of independent miners swarmed in. Chaotic, illicit mining—unauthorized by the owners of the land—became rampant, and large quantities of small, inexpensive tanzanites were readily available. Supplies of the gem burst back onto the international gem market. Previously high prices plummeted in the face of an abundance of stones.

Ralph Gabriner, courtesy Jane Bohan Inc.

Tanzanite prices rise and fall depending on the gem's availability. In the 1970s, tanzanites like this 2.00-ct. cushion cut were extremely expensive because Tanzanian government regulations limited production.

KEY CONCEPTS

Changes that take place in a gem's source country can drastically affect its availability and price.

Angelique Crown/GIA

Because Merelani Hill, Tanzania, is the only known source of commercially important tanzanite, the gem's supply is easily disrupted by floods and other natural disasters.

Supplies and prices stabilized in the 1990s and demand returned. Gem marketers embraced tanzanite and enthusiastically promoted tanzanite jewelry. Television home-shopping channels introduced tanzanite to millions of US homes.

In the late 1990s tanzanite mining conditions worsened. Sudden rains in 1998 brought catastrophic flooding that drowned many miners in underground tunnels. This was followed in 2002 by rumors that tanzanite was financing terrorist activities. This was later proved false, but it interrupted supplies of the gem once more.

Robert Weldon/GIA

The government of Tanzania has 50 percent control of the mine at Merelani Hill.

Since then, ownership of the tanzanite deposit has changed several times, and it's currently under the control of the Tanzanian government and private investors. You'll learn more about these changes and the current tanzanite market in Assignment 21.

Treatments and Disclosure

Until fairly recently, the average consumer wasn't aware that most commonly available gems are treated to make them marketable. If it weren't for treatments, many gems might be affordable to only the wealthiest consumers. For example, some unappealing white sapphire rough can be turned a beautiful blue by careful heat treatment. Treatment has become an important issue for many consumers, and media publicity about gem treatments can affect the sales of some colored stones.

KEY CONCEPTS

Treatments improve the marketability and availability of many gems.

Michel Viard/AFP

Heat treating gemstones to improve their appearance is a widely accepted practice. Thai workers seal sapphires in ceramic pots before plunging them into an oven.

Michel Viard/AFP

After treatment, the stones glow from the intense heat.

The emerald market suffered from negative attention in the 1990s (left) when consumers learned that sellers were not disclosing that most emeralds were treated to improve clarity. And as recently as 2015, some major retailers were found to be selling glass-filled rubies without proper disclosure (right). Issues of treatment disclosure continue to surface in the industry.

KEY CONCEPTS

In spite of treatment that's sometimes extensive, emerald is the number one colored stone by value imported into the US.

Most consumers accept gem treatments if they're ethically disclosed and explained in a positive way.

Emerald is an example of the way treatment and public information issues can affect sales. As you'll learn in Assignment 15, most emerald rough is fractured by the stresses of formation and mining. As a result, most finished emeralds are treated in some way—usually by filling with oils or resins—to improve their apparent clarity. In the late 1990s, emerald treatments received the attention of the media, and the negative publicity reduced consumer confidence in that gem.

High-profile court cases and consumer unease about treatments affected emerald sales. In spite of this, gem importers brought about $143 million of cut emeralds into the United States in 2002. And emerald remains the number one colored stone import into the United States in terms of value.

Nomenclature, disclosure, and durability concerns are still an issue in the market today. In the early 2000s, a new type of fracture filling hit the market in the form of high–lead content glass in fracture-filled ruby. This material turned corundum with no gem value into material that could be marketed

GIA and Harold & Erica Van Pelt

When beryllium-diffused sapphires first entered the market their colors were primarily pink-orange and the treatment was not disclosed. It was later discovered that beryllium diffusion could result in many additional corundum colors.

Orasa Weldon/GIA, courtesy Stephen Lewis Solomon

Large quantities of lead glass–filled rubies have entered the marketplace. They offer low-price options for commercial quality but the treatment is not always disclosed.

Eric Welch/GIA, courtesy Traditional Jewelers

Gem treatments must be disclosed clearly and ethically to maintain consumer confidence.

John Parrish, courtesy Rafco International Gem Corp

This 10.77-ct. blue sapphire from Sri Lanka owes its fine blue color and high degree of transparency to heat treatment.

in large volumes. At about the same time, a new type of diffusion treatment for corundum using beryllium entered the market, but it was undisclosed and sold as heat-treated sapphire. This led to a lack of confidence in the sapphire market once the true nature of the treatment was revealed.

Treatment is just one aspect of the fascinating world of colored stones. And if you approach the topic correctly, it isn't a barrier to sales. Most consumers readily accept gem treatments if they're ethically disclosed and explained in a positive way.

Eric Welch/GIA

With eLearning, you can complete assignment questionnaires online and get almost immediate feedback about your progress.

What's to Come

- How is this course structured?
- How can you get the most benefit from this course?

The *Colored Stones* course is made up of three main sections. Following this assignment's introduction to the world of colored stones, Assignments 2 through 6 show how a gem's formation affects its rarity and value and how a gem's properties affect its value and the way it's used in jewelry. You'll also read about synthetics and imitations and learn how the marketability of many gems can be transformed by treatment.

Assignments 7 through 11 introduce you to the factors used to judge gems—color, cut, clarity, and carat weight. You'll discover how gems reach the marketplace and how the gem business works.

Assignments 12 through 27 cover the major commercial gems in order of their importance. The assignments cover them all, from the Big 3— ruby, sapphire, and emerald—and other market basics like cultured pearls, jadeite, opal, quartz, tanzanite, topaz, tourmaline, and garnet, to lesser-known gems like spodumene and diopside. You'll also learn which gem colors the trade prefers and why.

Duncan Pay/GIA

To succeed in the complex colored stone industry, you need product knowledge as well as an appreciation of the mystical beauty that makes each gem unique.

eLearning Students: Checking Your Progress

The questionnaires you'll complete in *Colored Stones* are great ways to determine what you've learned and what you might have missed. The questionnaires also give GIA an idea of your progress.

Another terrific way to check your progress is to take another look at the Key Terms and Key Concepts at the end of each assignment. If you run across a term or concept that isn't clear to you, you can easily turn back to the part of the assignment where it's discussed in detail. Just look for its mention in the margin.

Taking the GIA Colored Stones program through eLearning allows you to learn essential product and market information in the environment of your choice.

Now that you've finished Assignment 1, complete the first questionnaire. It's important to do the questionnaires as soon as you finish the assignments, while the information is still fresh in your mind. That way, there's less danger that you'll forget important facts.

The Final Examination

There will be a proctored final exam at the end of the course. You must complete each questionnaire with a minimum score of 75 percent in order to take the final exam. You can schedule your final exam when you've completed and passed all the questionnaires. Then, to receive your *Colored Stones* certificate, you must score at least 75 percent on the final.

When you reach the end of the course, you can access the final exam instructions by clicking the link in the left-hand column of the eLearning page. Make sure you read them carefully. You don't need to schedule the final until you're nearly finished with the course.

Help Isn't Far Away

Your GIA instructor is just a quick email message or phone call away, Monday through Friday. GIA instructors are gemology experts with many years of trade experience. They'll answer your questions, clarify any parts of the text that you're unsure of, and help you with study hints. You'll also get feedback from your instructor in the form of comments that accompany the answers to your questionnaires. Save these comments to refer to when you review for the final exam.

By using all the resources available to you as you progress through this course—and others you might take in the future—you'll get the most out of your GIA eLearning experience.

Now it's time to take the next step in your journey through *Colored Stones*. Because the way a gem forms has such an impact on its rarity and eventual value, Assignment 2 concentrates on formation and mining. You'll see why some gems are fairly plentiful—and therefore inexpensive—while others are much more rare and costly.

KEY CONCEPTS

Most gems are minerals.

To be a gem, a mineral must be beautiful, durable, and rare.

Many colored stones are mined by independent miners using small-scale mining methods.

An appealing name can make a gem much easier to sell.

Changes that take place in a gem's source country can drastically affect its availability and price.

Treatments improve the marketability and availability of many gems.

In spite of treatment that's sometimes extensive, emerald is the number one colored stone by value imported into the US.

Most consumers accept gem treatments if they're ethically disclosed and explained in a positive way.

Key Terms

Amorphous—Lacking a regular crystal structure.

Atom—The basic structural unit of all matter.

Chemical composition—Kinds and relative quantities of atoms that make up a material.

Chemical element—A substance that consists of atoms of only one kind.

Crystal structure—Regular, repeating arrangement of atoms in a material.

Disclosure—Clearly and accurately informing customers about the nature of the goods they buy.

Facet—A flat, polished surface on a finished gem.

Gem species—A broad gem category based on chemical composition and crystal structure.

Gem variety—A subcategory of species, based on color, transparency, or phenomenon.

Group—A family of gems from several closely related mineral species.

Inorganic—Composed of, or arising from, non-living matter.

Mineral—A natural, inorganic substance with a characteristic chemical composition and usually characteristic structure.

Natural gems—Gems produced by natural processes, without human help.

Organic—Produced by, or derived from, a living organism.

Phenomenon—An unusual optical effect displayed by a gem.

Rock—A natural material composed of masses of mineral crystals of one or more kinds.

Silicate—A mineral that contains the elements silicon and oxygen.

Source—A gem-producing locality.

Questions for Review

- What are gems made of?
- What is a mineral?
- How do gemologists classify gems?
- How are mining and marketing different for diamonds and colored stones?
- How does the supply of a gem affect its marketability?
- How do treatments impact the sales of certain colored stones?
- How is this course structured?
- How can you get the most benefit from this course?

Gemstone Formation and Mining

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Welcome to *Colored Stones* Assignment 2. With the knowledge you gain from this assignment, you'll be able to:

- Understand the geological conditions necessary for gem formation.
- Describe the various gem formation processes.
- Define the different types of gem and mineral deposits.
- Understand the political and economic factors that affect gem mining costs.
- Communicate the methods used to find and evaluate gem deposits.

Eric Welch/GIA, courtesy Piteiras Mine

A miner monitors the unloading of emerald ore at the Piteiras mine in Mina Gerais, Brazil.

Gemstone Formation and Mining

Gemstones are the very best nature has to offer: beautiful, rare, and durable. But some gemstones are more rare than others, and differences in rarity have a lot to do with differences in value.

The rich green of a fine emerald is a rare sight compared to the abundant quantities of pale amethyst and treated blue topaz that you see at many trade shows or jewelry stores. And because there are many more amethysts and topazes than there are fine emeralds, the emeralds are far more expensive.

Ruby and garnet are both red gems, but rubies are far more valuable than garnets. This is due to a combination of reasons. Color is one: The intense red of a fine ruby eclipses even the best red garnet.

Rarity is another reason. Red garnets can form almost anywhere rocks are subjected to heat and pressure. As a result, the earth yields vast reserves of red garnets, and large stones aren't particularly scarce. But ruby formation requires precisely the right conditions, which exist only rarely. So rubies, especially large ones, are much rarer.

Jeffrey Scovil, courtesy Bill Larson Collection

This fabulous specimen consists of rough ruby crystals perched on white marble. It's the result of a rare combination of ingredients and geological conditions.

Shane McClure/GIA

Good-quality garnets come from vast deposits of metamorphic rock and are much more abundant than rubies.

The rules of supply and demand also apply. Since the supply of ruby is limited, the demand for ruby keeps prices high. On the other hand, there are plenty of red garnets to meet the demand for that gem, so garnet prices stay lower.

In this assignment, you'll learn how gems form within the rocks of the earth. You'll learn that a gem deposit is the result of a rare and unique combination of events. You'll find out that gemstone crystals only form if the right chemical ingredients are available at the exact moment when the pressure and temperature are right. Then they have to be allowed enough time and space—again, under the right conditions—to grow. You'll also learn that, once the gems are formed and deposited, it's extremely challenging to find and extract them from the earth.

No matter what part of the industry you're in, you can use the knowledge found in this assignment. Wholesale or retail, your career will benefit greatly from an understanding of how gems form and the lengths that people have to go through to find and mine them.

The Restless Earth

- What causes the movement of the earth's crust?
- What geological conditions are best for gem formation?
- What are the major rock formation processes?

KEY CONCEPTS

Rocks are the raw materials of gemstone formation.

Over billions of years, the ceaseless forces that shape our planet's surface have built and worn down huge mountain chains—crushing, melting, and changing vast volumes of rock in the process. Every time heat and pressure force rocks to change, there's potential for gem formation. And rocks are the raw materials of that process.

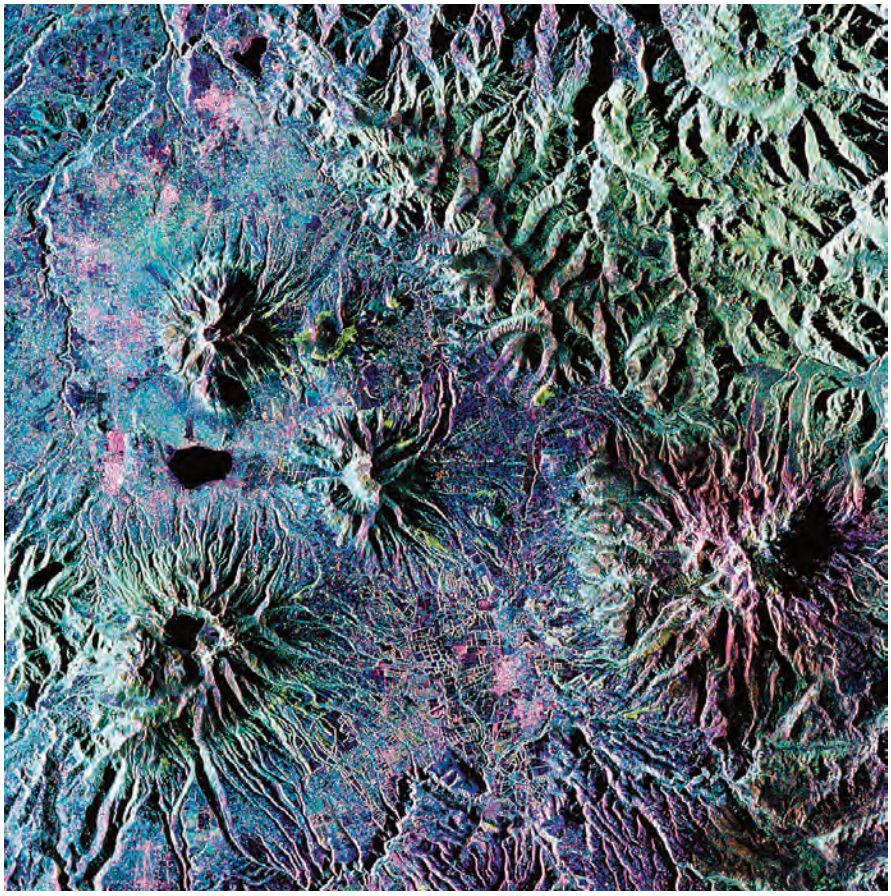
Geology—the science of the earth—is an important tool for prospectors. It helps them decide where to look for new gem sources. Geologists and gem prospectors know that deposits of certain colored stones are associated with certain types of rock. For example, they know that some sapphires are associated with basalt, and some rubies with marble. This knowledge helps them narrow down the search for these gems.

The Earth's Inner Structure

The earth's surface is constantly in motion, driven by heat deep beneath it. The volcanoes that puncture the planet's surface and the earthquakes that shock us with their violence reflect the earth's immense inner forces. Gem formation is intimately linked with these dynamic geological processes.

A look into the earth's interior will help you understand its surface dynamics. The *crust* is the outer surface. Its thickness ranges from about 5 km to 40 km (3 to 25 miles). It can be much thicker under mountain ranges, and it's thinnest under the oceans.

Crust—The surface and outermost layer of the earth.



PhotoDisc/StockTrek

The Andes Mountains—the giant South American mountain range seen here in a satellite image—were formed by huge geological forces over billions of years. Those same forces contribute to the formation of gems.

Peter Essick/Aurora Photos/Alamy

Violent forces are at work beneath the earth's surface. The San Andreas Fault in California marks the junction between two plates of the earth's crust. It's an area of massive earthquake activity.

Karen Kasmauski/RGB Ventures/SuperStock/Alamy

The battered remains of a bus that was charred by a fiery tide of volcanic rock are an outward sign of the immense heat and pressure deep within the planet.

Mantle—A layer between the earth's crust and its core.

Core—The earth's innermost layer.

Below the crust is the *mantle*. It's the main bulk of the earth, and it's many times thicker than the crust: about 2,885 km (1,790 miles) thick. Some sections of the mantle are partially molten (melted), creating conditions that can lead to periodic surface eruptions.

Beneath the mantle is the *core*, which consists of a molten outer layer about 2,270 km (1,410 miles) thick surrounding a solid central interior (mostly composed of iron, with some nickel) that's 2,400 km (1,490 miles) in diameter.

If you think of the earth as a peach, the core would be the pit, the crust its skin, and the mantle would be pretty much everything in between. Most colored stones form in the outermost layer of the earth, in the continental—not oceanic—crust.

KEY CONCEPTS

Most colored stones form in the earth's continental crust.

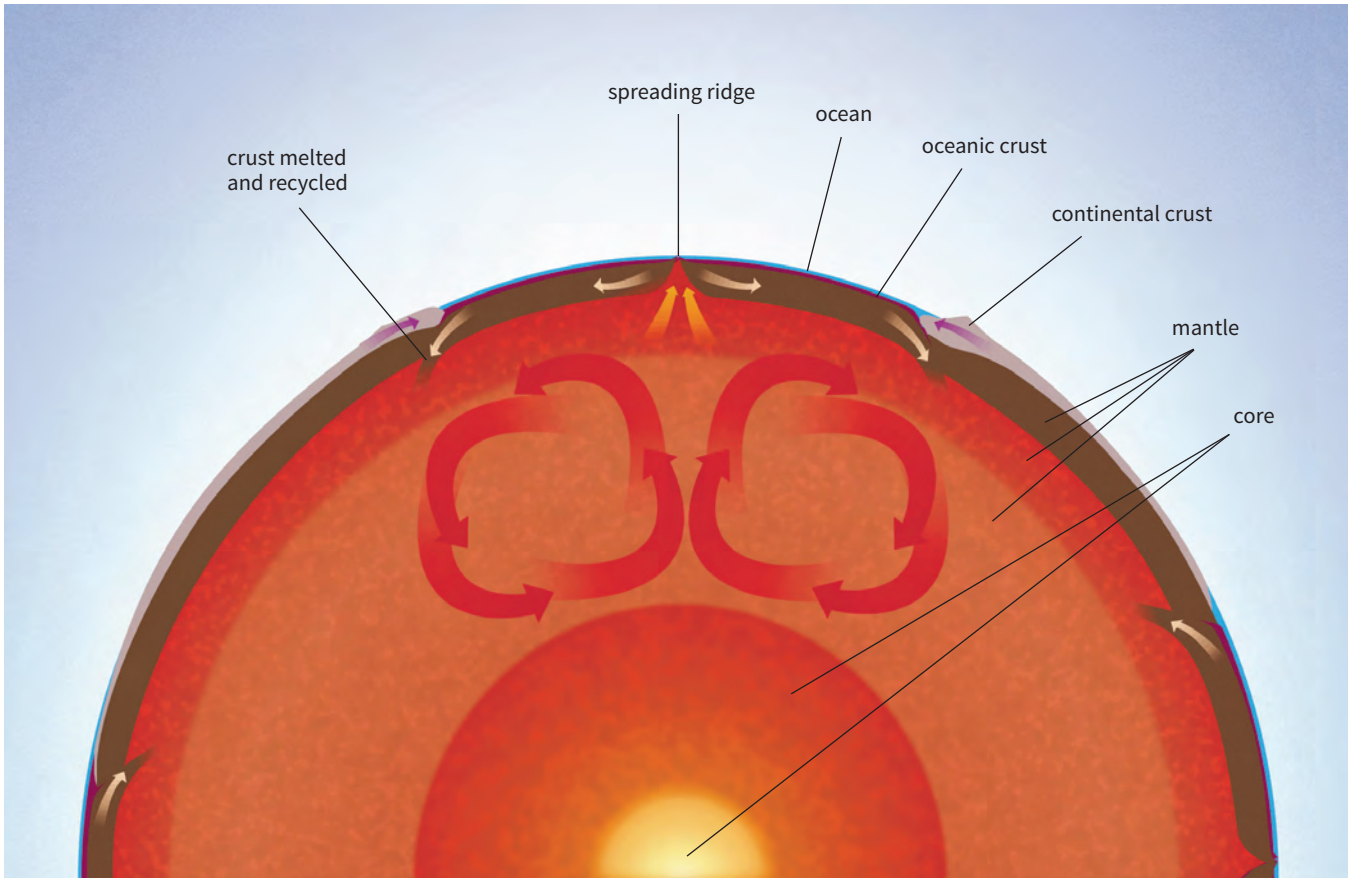
Plate Tectonics

The crust beneath your feet feels cool and solid, but appearances are deceiving. The heat is enormous in the earth's interior. And heat and pressure increase with depth. The earth's crust and part of the upper mantle are like a thin, rigid skin. But at a depth of about 70 km (40 miles) beneath the surface, pressure and temperature are just right for a weak molten layer to exist. In that layer, heat from the earth's interior keeps the molten rock, called *magma*, in constant motion.

Magma—General term for any molten rock.

The outer layer of the earth's crust is not uniform or continuous. Riding on the layer of magma, it forms a moving jigsaw puzzle of rigid *plates* that interact with one another.

Plate—A section of the earth's rigid outer crust.



Peter Johnston/GIA

The earth's crust is constantly breaking up and reforming, pushed by mantle convection. Heat from deep beneath the planet's surface forces magma to rise. Some of it escapes through spreading ridges to form new oceanic crust. In turn, the new crust pushes older crust to the margins of continents, where it's melted and recycled.

Plate tectonics—Study of the formation, structure, and movement of the plates of the earth's crust.

Mantle convection—Circulation in the mantle that drives the movement of the earth's plates.

Bryan Lowry/Alamy

Like a miniature cross-section of the earth's layers, this Hawaiian lava tube consists of red-hot magma covered by a thin solidified crust.

Peter Johnston/GIA

Just like in this illustrated pot of bubbling soup, heat in the earth's mantle causes circulating currents that constantly heat up, rise, cool, then sink to the bottom to be heated again.

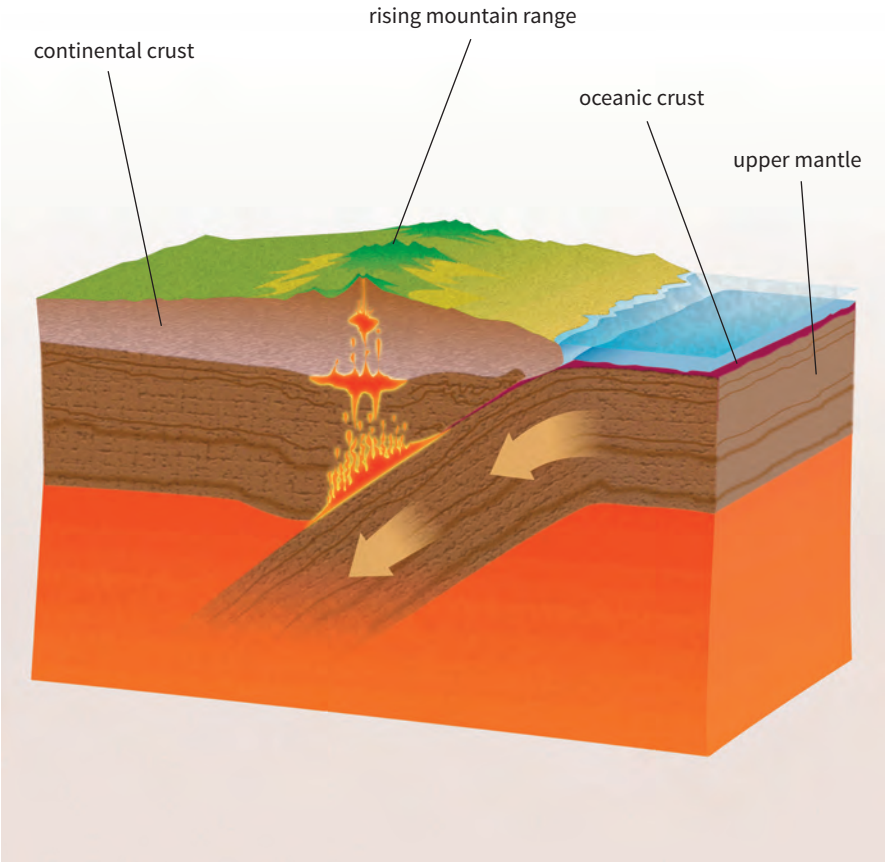
Most of the heat that moves the plates comes from the constant decay of radioactive elements deep within the earth. The volcanoes that dot the earth's surface act like valves to release pressure and vent some of the built-up heat. But that alone isn't enough. Hidden from view under the oceans, a much larger process goes on, driven by movement of the magma within the mantle.

The earth's plates are constantly—and over billions of years—breaking up and reforming, like the cooling skin on hot soup. The study of the movement of the earth's plates is called *plate tectonics*. Plate tectonics explains the pattern of mountain ranges, volcanoes, oceans, and gem deposits across the earth's surface.

As magma heats up deep in the mantle, it expands and rises. Eventually it cools, contracts, and falls back deep into the mantle to begin the process again. This cycle of heating and cooling, rising and falling is called convection, and it takes place constantly within the mantle. *Mantle convection* creates the circulating currents that move the plates.

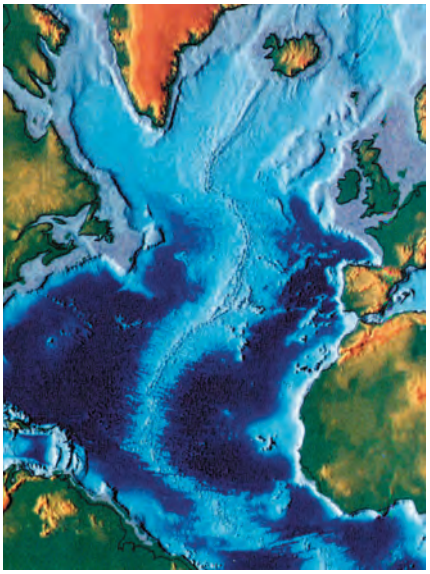
Mantle convection causes the opening of giant fissures in the earth's crust, in areas that geologists call spreading ridges. The best known of these is the Mid-Atlantic Ridge, which stretches for thousands of miles under the Atlantic Ocean. There, as the force of the convection process splits the plates apart, hot rock from the mantle rises into the split and forms new crust. The process adds new crust at a rate of only a few centimeters a year. Spreading ridges release much of the earth's inner heat.

The production of new crust is constantly balanced by a corresponding destruction and recycling of existing crust. The part of the cycle that melts and recycles the earth's crust is very interesting to gemologists because it produces some of the best conditions for gem formation.



Peter Johnston/GIA

Subduction recycles the earth's crust. While new crust is produced at spreading ridges, older crust descends at the margins of some of the continents, in areas called subduction zones (shown here). As the plates grind together, rocks buckle and melt into mountain ranges punctuated by volcanoes and earthquakes. Many different types of rocks are brought together at subduction zones, creating fertile conditions for gem formation.



NGSD/NOAA

The mid-Atlantic ridge, seen in this computer-enhanced satellite image, is a giant opening in the middle of the Atlantic Ocean. It marks a place, thousands of miles long, where magma rises from the earth's mantle to form new oceanic crust.

When Continents Collide

Volcanoes and earthquakes provide vital clues to the earth's turbulent inner workings, and to locations where crust is being formed or recycled. When mantle convection drives the earth's plates together, the action compresses vast volumes of rock. The colliding plates buckle and crumple, raising mountains. Or one plate is forced to sink under the other, into the mantle. Geologists call the latter process *subduction*.

Subduction—A process that occurs when two of the earth's plates collide, forcing one under the other.

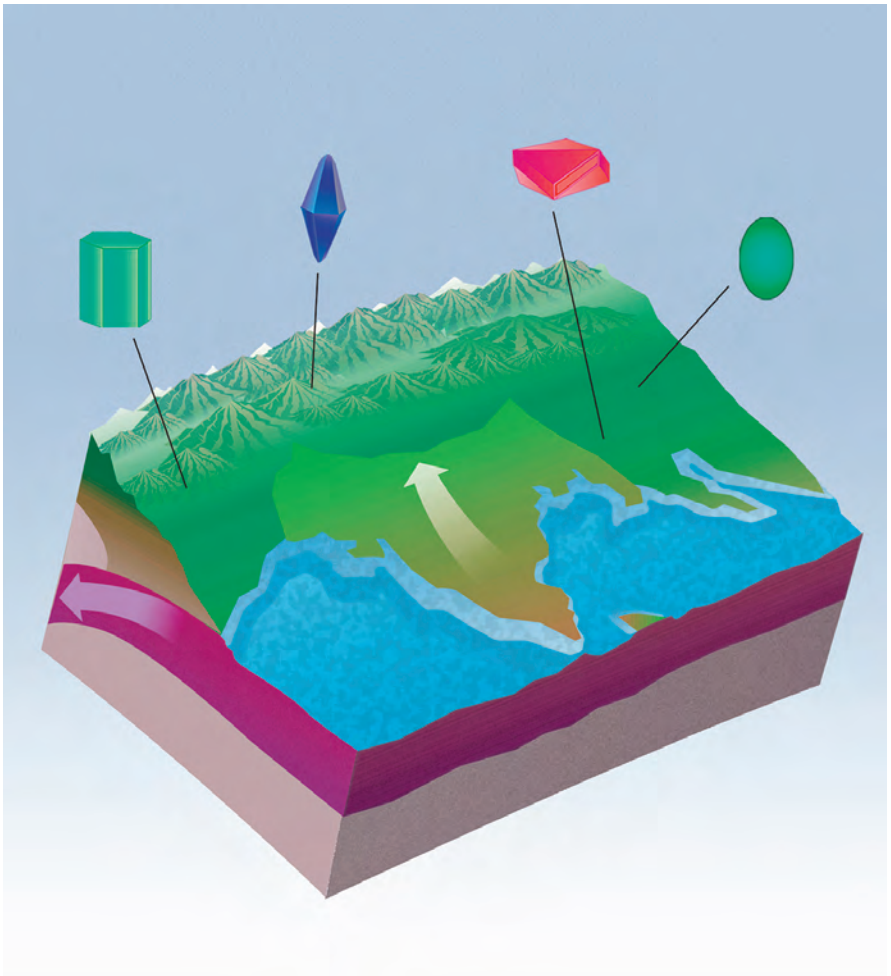
The subduction process melts and recycles the crust. At the same time that new crust is produced at the spreading ridges, existing crust is consumed at subduction zones. An example of a modern day subduction zone is the western coast of South America. The volcanoes of the Andes Mountains sit directly above the plate that's sinking under the earth's mantle. Molten rock from this melting plate pushes upward through the continental crust to the surface, making the volcano chain highly active.

Emerald
Panjshir Valley, Afghanistan

Sapphire
Kashmir. India

Ruby
Mogok, Myanmar

Jade
Uru River, Myanmar



Peter Johnston/GIA

The Himalayas—the world's largest mountain chain—are rich in gem deposits. Raised by the collision of India with the rest of Asia, the growing chain was a fertile environment for gem formation. Deposits include emeralds in Afghanistan and Pakistan, rubies in Nepal and Myanmar, and Burmese jade.

Gems and Mountains

Orogenic belt—A long, widespread area in the earth's crust where tectonic events cause major structural changes, often forming mountain ranges.

Continental collisions and subduction typically result in major structural changes to the earth's crust, creating long, widespread areas called *orogenic belts*. These areas often form vast mountain ranges. At the same time, the forces involved melt and transform the area's rocks. This causes new minerals to appear, creating excellent potential for gem formation. Most of the world's ruby, emerald, tourmaline, topaz, and garnet form in the heat and pressure of mountain building.

KEY CONCEPTS

Geological conditions during mountain building are favorable for gem formation.

The Himalayan mountain range, for example, is an enormous crumpled junction that marks the long, slow impact between India and the rest of the Asian continent. A wide variety of gem deposits dots these giant mountains from east to west: emeralds and rubies from Afghanistan and Pakistan; fine blue sapphires from Kashmir, India; rubies from Nepal; and rubies and jade from Myanmar (Burma).

Duncan Pay/GIA

The ancient mountains of Brazil yield many important gems. At Brazil's Belmont mine, a truck enters one of the mine's tunnels to collect ore for processing. Tunnels must be wide and deep enough to accommodate large trucks like this one.

Andrew Lucas/GIA

The Belmont mine, in Brazil, is an important source of premium-quality emeralds like this 29.8-gram specimen.

Rock cycle—A constant formation and recycling process that creates new rock from old.

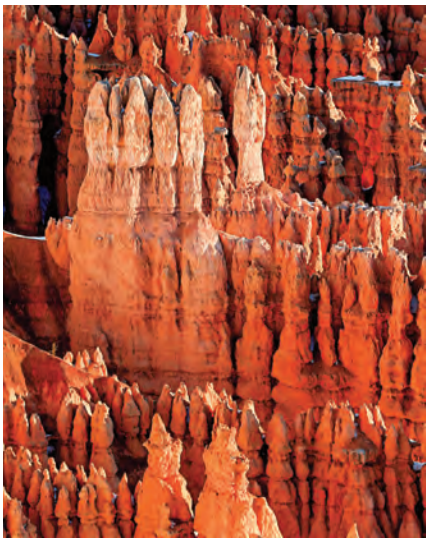
Erosion—The wearing away and transport of rock materials by natural forces.

Gemstones like peridot and sapphire reach the earth's surface when molten rock transports them from deep within the crust or even from the mantle. This can happen during subduction, when ocean crust descends and melts beneath a continent. These types of deposits exist in the inland areas behind a mountain range. Many of the corundum deposits of Southeast Asia—Thailand, Vietnam, and China—are associated with volcanic rock, and are believed to be deposits of this type.

The Rock Cycle

You've seen how enormous continental collisions can continuously reform and recycle the earth's crust. A similar process also takes place on a smaller scale.

Old rocks are broken down and new ones are created during the *rock cycle*. If the rocks are deep underground, they're altered or melted by the earth's inner forces. If they're at the surface, *erosion*—exposure to water, wind, and other environmental conditions—breaks them down. The broken-down rocks are then buried, altered by pressure, or melted by high temperatures to begin the cycle again. Thus, the stages of the rock cycle can include all three rock formation processes: igneous, metamorphic, and sedimentary.



Steve Geer/iStockphoto.com

At Bryce Canyon, Utah, towers of resistant rock rise from the desert floor to mark a battleground of erosion. Over millions of years, wind and water have stripped away the less resistant materials to produce the patterns seen in the landscape today.

KEY CONCEPTS

In most igneous rocks, large crystals indicate slow cooling, while small crystals indicate rapid cooling.

iStockphoto.com

Igneous rocks begin in a molten or semi-molten state and become solid as they cool. Molten material lurks beneath a thin cooled crust in this lava flow in the volcanic Hawaiian island chain.

Igneous rock—Rock formed by the crystallization of molten material.

Metamorphic rock—A category of rocks that have been altered by heat and pressure.

Igneous Rock Formation

Igneous rocks start out in a molten or semi-molten state and become solid when they cool. The size of a rock's crystals can be an indication of how long the rock took to cool. This is directly related to the depth where the rock solidified. Large crystals generally indicate slow cooling that took place deep underground. Small crystals typically indicate rapid cooling closer to the surface.

Two of the most widespread igneous rocks are granite and basalt. Granite is rich in lighter elements like silicon, oxygen, and aluminum. Basalt, which is rich in iron and magnesium, is much denser. The continental crust is composed mostly of granite, whereas the oceanic crust is mostly basalt.

Granite has large interlocking crystals, while basalt contains a multitude of tiny crystals. This tells you the granite had more time to crystallize than the basalt, which cooled quickly close to the earth's surface. As you'll see later in this assignment, the igneous activity associated with granite can produce a wide range of gems such as topaz, tourmaline, and spodumene. Basalt can carry gems like corundum and peridot to the surface, but doesn't produce the gems.

Metamorphic Rock Formation

Heat and pressure can transform old rocks and minerals into new ones. Rocks altered by heat and pressure are called *metamorphic rocks*. The "new" rocks are then stable under the new conditions. Ruby, sapphire, garnet, and lapis lazuli can all be produced by changes in temperature and pressure, as long as the right materials are available.

Lynnae Lowe/iStockphoto.com

Sedimentary rocks—formed from the eroded remnants of older rocks—represent millions of years of recycling. The sediments in these layers were continuously buried and compacted under newer deposits.

Eric Welch/GIA, courtesy Belmont Mine

A miner searches through emerald-bearing ore at the Belmont mine near Itabira, Brazil, where emeralds are mined from a metamorphic rock called schist.

Marble is limestone that's been altered by heat and pressure. If the limestone contains aluminum impurities, ruby and spinel might form as new minerals during metamorphism. Geologists believe that Burmese and Vietnamese rubies formed in this way.

Schist is metamorphic rock with a distinct alignment of mineral grains. Often tightly folded and contorted, it's the host rock for most of the world's emerald deposits. Schist in Zimbabwe, Brazil, Zambia, and Madagascar provide some of the world's largest commercial emerald sources.

Eric Welch/GIA

A close-up shows dark green emerald crystals growing through a chunk of schist.

Sedimentary Rock Formation

Sedimentary rocks are produced from the weathered products of existing rocks. Many different conditions can break rocks down. Frost shatters the high mountain peaks, and the action of air and water decomposes many minerals that bind rocks together. Even an apparently hard, durable rock like granite can weather rapidly in tropical areas with high rainfall. The wetter and warmer the climate, the faster the rock will disintegrate. Rainfall also helps carry the broken-down materials away.

Sedimentary rock—Rock produced from the eroded and weathered remains of existing rocks.

Erosion is the great leveler: With the help of gravity and water or wind, it redistributes rocks from high mountains to low-lying plains, leaving deposits of weathered sediment. Eventually—over many millions of years—the sediments accumulate in thick layers. The pressure from above compacts the layers and hardens them into rock.

Some notable gems form in sedimentary rocks close to the earth's surface, many at near-normal pressure and temperature. Some examples of these are opal, malachite, and turquoise. Sedimentary processes also produce limestone as well as sandstone, which is mostly quartz.

How Gems Form

- Which gemstones are associated with igneous rocks?
- What crucial role does superheated water play in gem formation?
- Which gems are associated with metamorphic rocks?
- Which gem deposits are formed by sedimentary processes?

Now that you've learned the differences between igneous, metamorphic, and sedimentary rocks, it's time to look at the specific colored gemstones that come from each process.

Gems can form directly within igneous rock (moonstone, for example) or from gasses and hot fluids released from molten rock (topaz, red beryl, tourmaline). They might also be carried to the earth's surface from the mantle or from deep in the crust by violent eruptions (diamond, peridot, sapphire).

Some gems (ruby, garnet, and spinel) are produced by metamorphism, when heat and pressure cause rocks and minerals to alter without melting. Large bodies of molten rock are produced during mountain building, which provides the heat source for large-scale metamorphism.

Alan Jobbins

Many different gems form from igneous processes. Moonstone—a type of feldspar—can form directly in volcanic rock. These examples are from Sri Lanka.

Jeffrey Scovil, courtesy John Barlow

So far, only one source—in Utah's Wah Wah Mountains—produces red beryl. It forms from gasses released by a volcanic rock called rhyolite as it cools.

Shane McClure/GIA, courtesy Pala International

Peridot is one of the most important volcanic gems. Like diamond, it's carried to the earth's surface by violent eruptions. These crystals are from Pakistan, high in the Himalayas.

Gem deposits that are found in sedimentary rocks have one thing in common: the action of water. Water moving through rocks close to the earth's surface can dissolve and redeposit minerals. If mineral-rich water encounters the right rocks, the reaction can form gems like turquoise or malachite.

When gems are released from their source rocks by erosion, water plays the key role in sorting and concentrating them in deposits profitable enough to mine.

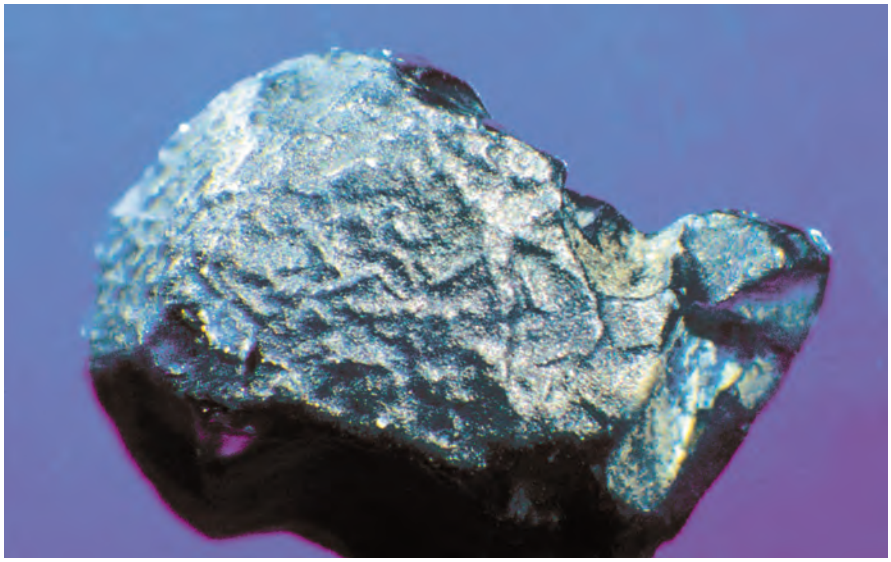
Gems from Igneous Rocks

A volcano is the most visible sign of igneous activity. Some gems come from *volcanic* rocks that might give up their formed gems to other rocks that act as carriers. Hot mineral-rich solutions from underground magma can also be crucial for the formation of certain gems.

Volcanic Formation and Delivery

Lava erupting from fissures and volcanoes can be a source for gemstones. Moonstone, for example, can form directly in magma. Topaz and rare red beryl can crystallize in volcanic rocks from the gasses that the magma releases during the final stages of cooling. This gas crystallization process is known as *pneumatolysis* (noo-ma-TOL-i-sis). But magma and expanding volcanic gasses are relatively minor sources of gems.

Although gems like ruby, sapphire, peridot, and zircon are associated with volcanic rocks, scientists don't believe they formed directly from the rock itself. Instead, they were brought up from great depths (up to 100 km or 60 miles) as "passengers" in the surrounding magma.



Chris Smith/Gübelin Gemmological Laboratory

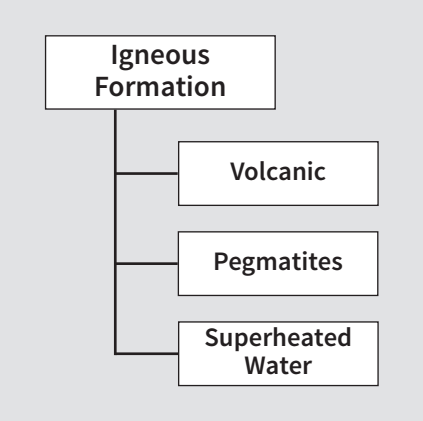
The outer surface of this rough sapphire crystal was scarred by its journey to the surface. Its volcanic delivery left it with an etched or "glassy" crystal surface and lack of recognizable crystal form.

KEY CONCEPTS

Some types of volcanic rock can transport existing gems from deep in the crust to the earth's surface.

Volcanic—Pertaining to igneous activity at the earth's surface, where magma erupts through a volcano or fissure.

Pneumatolysis—Crystallization of minerals from a gas.



Andrew Lucas/GIA

At many deposits in Thailand and Cambodia, volcanic activity brought rubies and sapphires to the surface. Weathering quickly broke down the surrounding alkali-basalt into rich red soils. This released the corundum into the streambed gravels, which miners wash to recover the gems.

Most of the world's sapphires are weathered from basalt, but scientists are divided on their origin. Many agree that corundum doesn't form directly in the basalt, and propose that a special type of volcanic rock—called alkali-basalt—acts as a carrier to propel existing corundum crystals to the surface. Alkali-basalt comes from deeper levels in the earth than normal basalt. Scientists believe its source might be the oceanic crust that descends deep beneath a subduction zone.

Xenocryst—A "foreign crystal" that forms in unrelated rocks and is brought to the surface as a passenger in magma.

As the basalt rises upwards, it plucks the corundum crystals from deep in the crust and transports them to the surface. "Glassy" or etched crystal surfaces are an unmistakable sign that sapphire crystals were corroded by this volcanic activity. Because the crystals didn't originate in the volcanic rock, they're given a special name: *xenocryst* (ZEE-no-crist), which literally means "foreign crystal."

Although less than 10 percent of the world's basalt is of this type, alkali-basalt is often associated with gem-quality sapphire. Deposits include Australia, Thailand, Cambodia, Nigeria, China, and Southern Vietnam. Highly vulnerable to weathering in a tropical climate, corundum-bearing alkali-basalt decomposes rapidly, leaving gem crystals to accumulate in river gravel.

Gems from Pegmatites

Some of the biggest and best crystals in nature come from special igneous rocks called *pegmatites*, which are usually associated with the granites that make up the cores of mountains. When they form, they follow the fractures in their surrounding rocks, so they can be thin and twisted in shape.

Pegmatite—An igneous rock typically formed from cooling, once-molten granite that follows fractures in its surrounding rock.

Pegmatites typically form from large masses of cooling, once-molten granite. (Their formation process is called the pegmatite stage.) Granite contains tiny percentages of exotic elements like lithium, beryllium, boron, manganese, and fluorine. These elements usually don't become part of minerals like quartz and feldspar, which make up the bulk of the granite. Once quartz and feldspar start to crystallize, the exotic elements are forced to the top of the cooling granite. There, they become concentrated.

Finally, the portion of the granite that contains the exotic elements is squeezed into fractures in the surrounding rock. As the pegmatite comes into contact with the surrounding rock, it cools from the outside. This creates layers of different minerals with the exotic elements concentrated in the still-hot center. These exotic elements crystallize last, forming pockets of gem minerals.

Crystals in pegmatite come in a range of sizes, but they're usually much larger than the crystals in the parent granite. The outer layers of a pegmatite are "chilled" when they come into contact with the surrounding rock. The chilled layers act as insulators, which can allow time for the development of large crystals.

KEY CONCEPTS

Some of the largest and most perfect gem crystals come from pegmatites.

Alan Jobbins

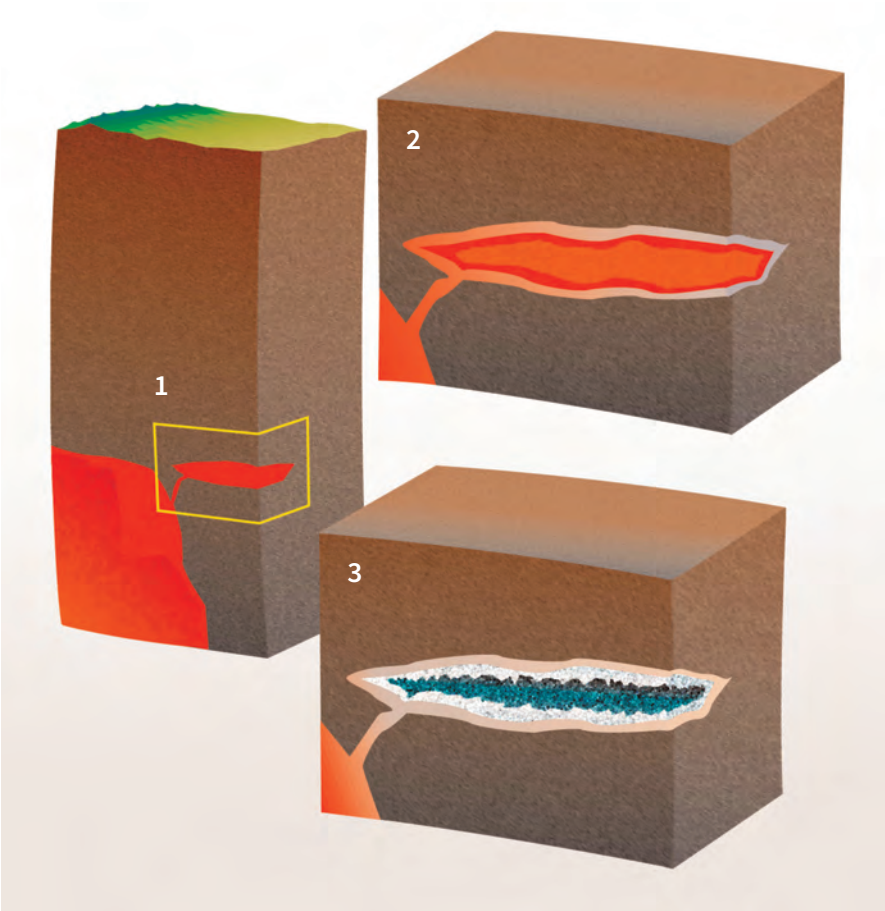
These spectacular museum-quality tourmaline crystals might be left unfaceted and sold to collectors.

Alan Jobbins

This pegmatite vein shows pink mica in the center and black tourmaline crystals growing around the margins. The thin brownish outer margin insulated the interior and allowed large crystals to form.

Crystal: Jeffrey Scovil, courtesy Wayne Thompson Minerals; cut stone: Robert Weldon/GIA, courtesy Pala International

These aquamarines—a spectacular 12.7-cm crystal (left) and a 13.10-ct. faceted gem (right)—represent the best that pegmatite pockets have to offer.



Peter Johnston/GIA

Pegmatites form when foreign elements become concentrated at the top of an igneous intrusion. When the intrusion cools and crystallizes, the elements that can't be contained any longer are pushed into cracks in the surrounding rock to form a pegmatite body (1). As the pegmatite cools, it begins to separate (2). Finally, if conditions are exactly right, the remaining elements crystallize into gem pockets (3).

While slow development was once thought to be the rule, recent research suggests that those large crystals might form much more rapidly than previously thought. Pegmatite melts contain many exotic elements along with water and other readily vaporized substances, collectively called volatiles. The volatiles are expelled as the magma crystallizes, making the melt more fluid and lowering the temperature at which crystallization begins. This keeps masses of smaller crystals from forming and sometimes allows a small number of crystals to grow to extremely large sizes. Modern experimental models of cooling and crystal growth rates show that some pegmatites crystallize very rapidly: in days to years, rather than in thousands to millions of years as previously believed.

Only a small percentage of pegmatites are gem-bearing, but they produce more kinds of gems than any other deposit. Many of the minerals they produce—including multicolored tourmaline, kunzite, aquamarine, and pink and yellow beryl—are prized by collectors as mineral specimens as well as by lapidaries as potential finished gems.

Eric Welch/GIA

Many colored stone mines are small-scale operations. This independent emerald miner is searching for gems in the Capoeirana area of Minas Gerais, Brazil.

Andrew Lucas/GIA

This small-scale topaz mine is located near Brazil's Ouro Preto.

While most gem-bearing pegmatites come from granite, there are rare corundum-bearing pegmatites in Tanzania, a country in East Africa, that do not. These are made mostly of feldspar, and they have a low silica content. They cut through a rock that "stripped" the silica out of the pegmatite, allowing the corundum to form.

Pegmatites are found all over the world, in open, rolling country, where erosion has exposed the roots of ancient mountain ranges. The world's most important pegmatite source is Minas Gerais in Brazil, which produces most of the aquamarine and tourmaline seen in the gem trade. Other important pegmatite localities are Namibia and Madagascar, as well as Maine and California in the US.

Gems from Superheated Water

Rich purple amethyst, imperial topaz, and the world's finest emeralds all come from a special type of *vein* deposit that's thought to be related to igneous activity.

Vein—A mineral deposit that occupies an existing fissure or fracture in the rock.

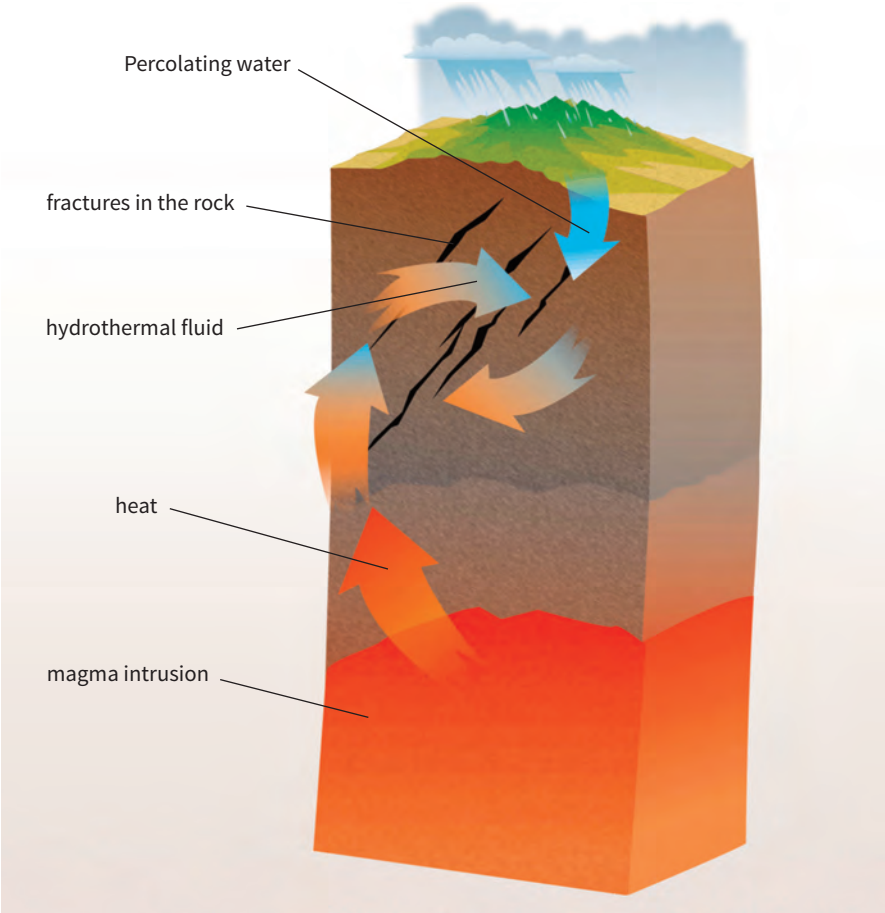
When hot magma rises through the earth's crust it doesn't always make it to the surface to erupt as a volcano, but sometimes cools underground to form a large igneous *intrusion* such as granite.

Intrusion—Large mass of igneous rock that crystallizes underground without reaching the surface.

As it cools, the hot rock gives off mineral-rich solutions and heat that cause the hot water from the granite to spread into the surrounding rocks. As the fluids spread, they pick up and carry elements from the granite and the surrounding rocks. As the solutions cool, they collect in fissures and cavities and contribute to the formation of new minerals. This results in the formation of mineral veins in the surrounding rock.

Bob Jennings/GIA

Hot, silica-rich solutions that rose through this fracture deposited a milky-white quartz vein as they cooled.



Peter Johnston/GIA

Hydrothermal gem formation is thought to be related to igneous activity. An intrusion—an underground body of hot rock—heats cool water that percolates down from the earth's surface or directly provides the superheated fluids on its own. Either process creates hot hydrothermal fluids that rise. These superheated solutions can dissolve and transport a wide variety of chemical elements that are suitable for building gems like amethyst, topaz, and—in rare circumstances—emerald. As the hydrothermal solutions rise, they cool. As they cool, they deposit dissolved minerals into fractures and openings in the rocks they pass through.

Hydrothermal fluid—Hot, high-pressure solution that can dissolve, transport, and deposit minerals from one place to another.

Superheated water can remove elements like beryllium and silicon from rocks. Under the right circumstances, it can also redeposit those elements elsewhere to build gem crystals. This mineral-rich pressurized hot water is known as *hydrothermal fluid*.

Water that's pressurized and heated to high temperatures can carry more minerals in solution than cooler water. Scientists who grow hydrothermal synthetic emeralds in the laboratory have understood this principle for decades, but nature did it first. (You'll learn about lab-grown emeralds later in the course.)

KEY CONCEPTS

Superheated, pressurized water can transfer elements in solution and redeposit them in veins to form gems.

Hydrothermal fluids often carry rare elements like beryllium, boron, or fluorine. If conditions are right, the veins might contain amethyst, or in rare circumstances, topaz or emerald. Key localities for hydrothermal gems are the Colombian emerald mines of Muzo and Chivor, and Ouro Preto, Brazil, which has the world's only known deposits of imperial topaz.

Karen Massier/iStockphoto.com

Steam rises from vents in Yellowstone National Park. Geysers are the surface expression of hydrothermal activity, and a clue that a large intrusion of molten rock lies below, fairly close to the surface.

Daniel A. Sauer, courtesy Amsterdam Sauer Jewelers

Topaz crystals come from hydrothermal veins, which start as fractures in the rock. A good haul for a day's work, this bag contains about 4 kg (9 lbs.) of rough topaz.

Eric Welch/GIA

The only known commercial deposits of imperial topaz are the hydrothermal veins near Ouro Preto, Brazil. Miners use water cannons and bulldozers to loosen gravel at the base of the mine. Scoopers then haul the material to the top for processing.

Jeffrey Scovil, courtesy The Collector's Edge

Many of the world's most fabulous emeralds come from hydrothermal veins at Muzo, Colombia. These rough crystals measure 1.80 cm.

Robert Weldon/GIA

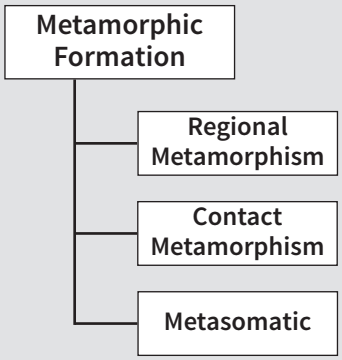
This fashioned emerald from Muzo weighs 5.70 cts.

Robert Weldon, courtesy Pala International

Tanzanite—the transparent blue variety of zoisite—is mined commercially in only one place in the world: Tanzania. It forms in metamorphic rocks. This crystal is still attached to its host rock.

Tino Hammid/GIA, courtesy Varujan Arslanyan

Grossular garnet is found in the metamorphic rocks of the Mozambique belt in East Africa. These are from Tanzania, and range in size from 1.19 cts. to 3.34 cts. The green ones are a variety of grossular called tsavorite.



Gems from Metamorphic Rocks

From fabulous rubies worth fortunes to humble red garnets worth only a few cents apiece, metamorphic gems grace jewelry of every price. The ancient mountains that run through much of eastern Africa form a huge tract of metamorphic rock that yields ruby, emerald, and alexandrite, as well as the spectacular newer gems tanzanite and tsavorite.

Gemstones formed by metamorphism crystallize in solid rock when temperature or pressure rises so high that the original minerals can no longer exist. They gradually change into new minerals that are stable under the new conditions.

Metamorphism can take millions of years. It's related to the earth's tectonic activities, which you learned about earlier. Massive forces drive the motion of the earth's crust, compressing and melting enormous volumes of rock. Vast bodies of granite form in the cores of developing mountains and provide the heat for transformation.

While metamorphism can affect large areas, smaller igneous intrusions can cause localized changes when both heat and fluids from magma create new minerals in the surrounding rocks. Because of the close connection between heated rock and metamorphism, it's often difficult to draw a sharp dividing line between igneous and metamorphic processes.

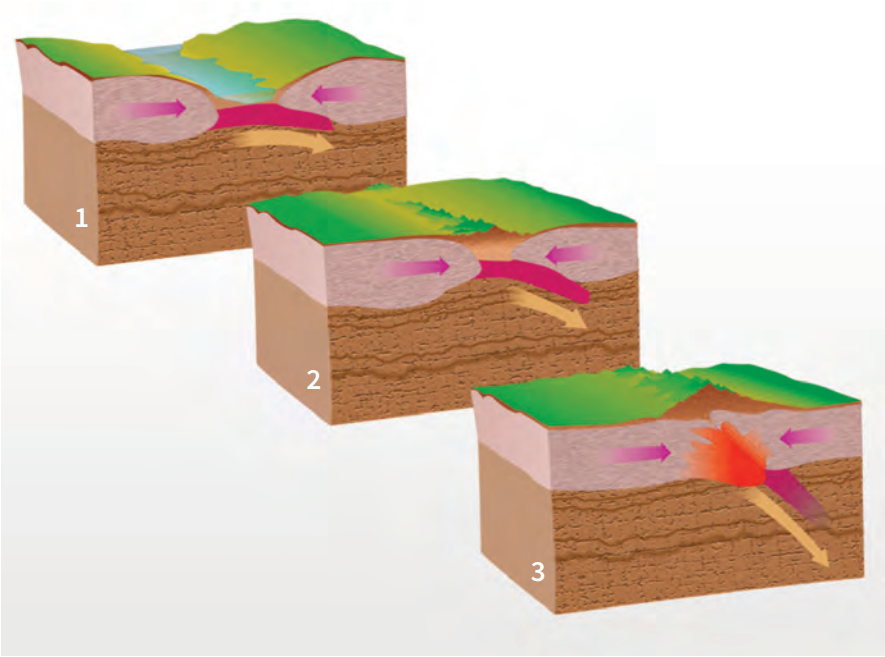
Although the distinction is not always absolutely clear, scientists divide metamorphic processes into two broad categories. Large-scale *regional metamorphism* affects whole mountain ranges, whereas small-scale *contact metamorphism* occurs in the zone surrounding intrusions of molten rock.

Jeffrey Scovil, courtesy H. Obodda

A fine 4.6-cm ruby crystal from Afghanistan shows the typical bright red appearance of rubies from marble, a metamorphic rock.

Regional metamorphism—Changes in rock type and minerals over a wide area, caused by heat and pressure of large-scale geological events.

Contact metamorphism—Localized changes caused by an igneous intrusion that takes place where the magma meets the surrounding rock.



Peter Johnston/GIA

As continents collide, vast bodies of rock are melted or transformed by heat and pressure. This diagram shows the three phases of that process. As two continents approach each other, oceanic crust is forced under the margin of one continent, and the ocean closes between them (1). As the continents come closer together, vast bodies of rock fold and huge masses of molten granite form the heart of the rising mountain range (2). The molten granites provide much of the heat for metamorphism, while the force of the collision folds rocks for hundreds of miles (3). Events like these produce many of the world's most famous gem deposits.

Tino Hammid/GIA, courtesy Neil Lane Inc.

Burmese rubies grace many of the finest jewelry items. Only bead prongs interrupt the cluster of ruby cabochons in this retro-style bombé ring attributed to Van Cleef & Arpels.

Although regional and contact metamorphism differ in scale and extent, they can both produce similar gem materials. They can also blend together, as they do in the ruby and sapphire deposits of Mogok (in Myanmar, once known as Burma). Both can have similar if not identical results and produce the same minerals.

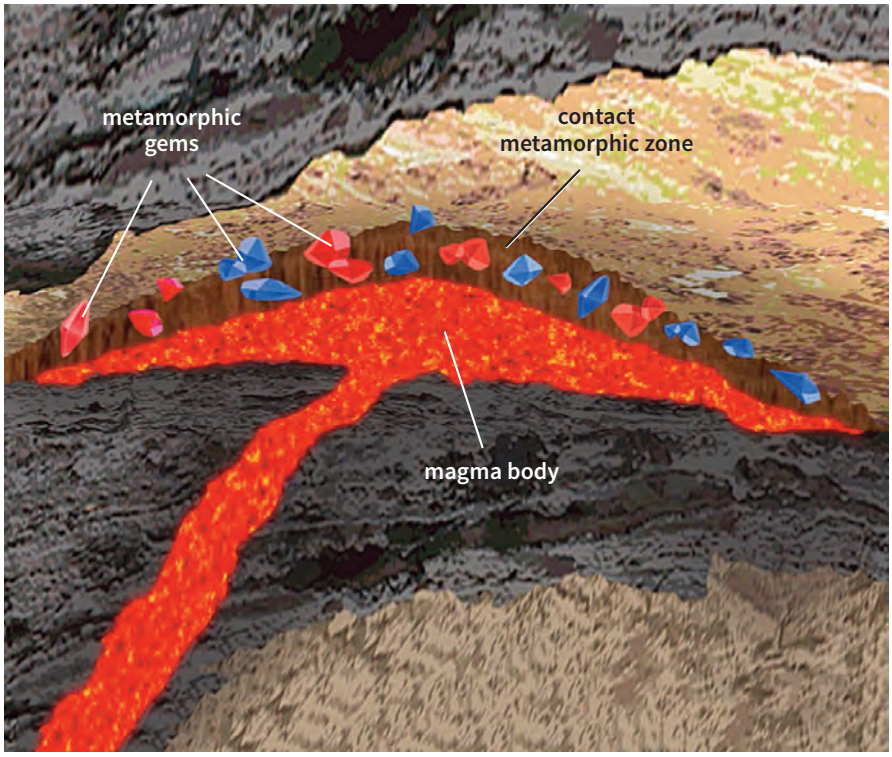
Burmese ruby arises from a special combination of metamorphic processes. At Mogok and other marble-related ruby deposits, gemologists think intense tropical weathering created layers of limestone with aluminum impurities. The composition of limestone can change dramatically when it comes into contact with molten rock.

Great thicknesses of other rocks buried the limestone over many millions of years. Collision between the Indian subcontinent and the rest of Asia thrust up a huge chain of new mountains, and Mogok became part of the Himalayas.

In turn, granites created by the heat and pressure of mountain building converted Mogok's limestone into marble. Then the metamorphic process acted on the marble's aluminum impurities, transforming them into the most coveted colored stones in history. Burma is a fine ruby's ultimate pedigree, worth a premium in the market.

Andrew Lucas/GIA

Myanmar's Mogok mines produce some of the world's finest rubies. Their gems are the standard by which rubies from other parts of the world are judged.



Peter Johnston & Joseph Kaus/GIA

Contact metamorphism occurs where molten materials meet the surrounding rock. It's smaller in scale than regional metamorphism, but the gems that result can be similar.

Andrew Lucas/GIA

Contact between a pegmatite vein and schist host rock at an emerald mine in Zambia offers the potential for emerald formation by a metasomatic process.

Vincent Pardieu/GIA

This ruby deposit in Montepuez, Mozambique, is thought to have resulted mainly from a metasomatic process, when magma-derived fluid interacted with rocks with low silica content.

Metasomatic Gem Formation

While metamorphism causes rocks to change while they are still mostly solid, a metamorphic process called *metasomatism* occurs when material is introduced from external sources, most often in hydrothermal solutions. This action changes the chemical composition and texture of the surrounding rocks by replacing existing minerals with new ones.

Metasomatism—A type of metamorphism where chemical changes in the minerals and rocks result from the introduction of material from external sources, often as hydrothermal solutions.

Possible sources of the solutions include large igneous intrusions or regional metamorphic formations, and the process often takes place where they contact the surrounding rock. During metasomatism, the minerals that make up the original rock are partially or completely replaced by new minerals, without any melting involved.

Currently, Mozambique is a prolific source of commercial- and fine-quality ruby. The deposit near Montepuez is thought to be the world's largest ruby source. The area's ruby formation seems to have resulted mainly from a metasomatic process, when magma-derived fluid interacted with rocks with low silica content.

Ruby formation can take place only within very limited pressure and temperature ranges, and only in the presence of a sufficient supply of aluminum, chromium, and oxygen. Northeastern Mozambique is located at the junction between two ancient mountain belts. Around 500 to 800 million years ago, a series of geological events created the ideal temperature and pressure for the formation of ruby, garnet, and other economically important minerals.

In practice it's often hard to draw distinct boundaries between igneous and metamorphic processes, especially where there's movement of hydrothermal fluids into the surrounding rock. Large-scale plate tectonics drives both igneous and metamorphic processes, which directly melt or transform vast volumes of rocks.

Courtesy A. Ruppenthal KG

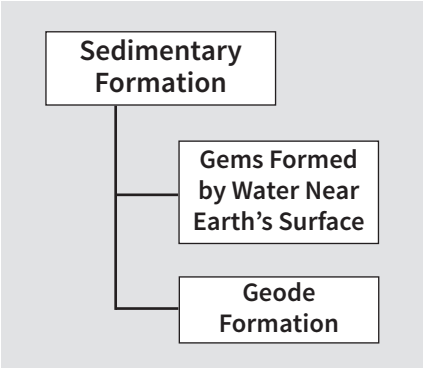
The domed folds of this malachite from Zaire, Africa, follow the contours of the cavity where it was deposited layer by layer by mineral solutions.

Tino Hammid/GIA, courtesy Laurie M. Donovan and L&R Wise Goldsmiths

This one-of-a-kind designer piece features a beautiful Australian boulder opal.

Gems from Sedimentary Rocks

Gems don't only form deep in the earth's crust. Water from the surface also plays an important role in the formation of many gem deposits. You've seen that very hot water at high pressures can move minerals in solution from one place and deposit them in another. The same is true of cooler water.



Gems Formed by Water Near the Earth's Surface

Given sufficient time, ordinary water—especially if it's acidic or heated—can actively dissolve rock, transport minerals in solution, and deposit them as new minerals elsewhere. Opal, turquoise, and rhodochrosite are soft but beautiful gems that form close to the earth's surface with the help of water.

Rainwater can combine with the carbon dioxide in the atmosphere to produce a weak acid. If this water seeps into the ground and meets sulfides like pyrite, it can make much stronger sulfuric acid, which can dissolve and transport many additional minerals.

Water carrying dissolved minerals can percolate through rocks and react with other minerals that are already present. The new combination can leave gems like turquoise, rhodochrosite, and malachite deposited in cavities, seams, and fissures.

Turquoise forms when acidic copper-rich solutions seep through and react with volcanic rocks that contain aluminum and phosphorous. Malachite forms when those solutions react with limestone. Rhodochrosite forms in a similar way to malachite, but the solutions need to be rich in manganese.

Arid regions with limited seasonal rainfall are ideal for the formation of opal deposits by evaporation. In one model, water percolates down through sediments or volcanic rocks rich in silica and carries the silica down to the water table during the rainy season. The silica-rich solutions fill cracks and voids in the rock, and when the water gradually evaporates during the dry season, silica is deposited as submicroscopic spheres in the open spaces in the rock. These tiny spheres provide the optical effect that gives opal its characteristic play-of-color. You'll learn about other theories of opal formation later in the course.

The finest opal in the world is mined from sedimentary rocks in the arid regions of eastern and central Australia, at Andamooka, Coober Pedy, Mintabie, Lightning Ridge, and White Cliffs.

Andrew Lucas/GIA

Play-of-color reveals seams of precious opal that formed in the arid regions of Australia.

Robert Weldon/GIA, courtesy Jack Lowell

When copper-rich mineral solutions contact volcanic rocks that contain sufficient aluminum and phosphorous, the reaction can result in turquoise formation.

The Big Picture

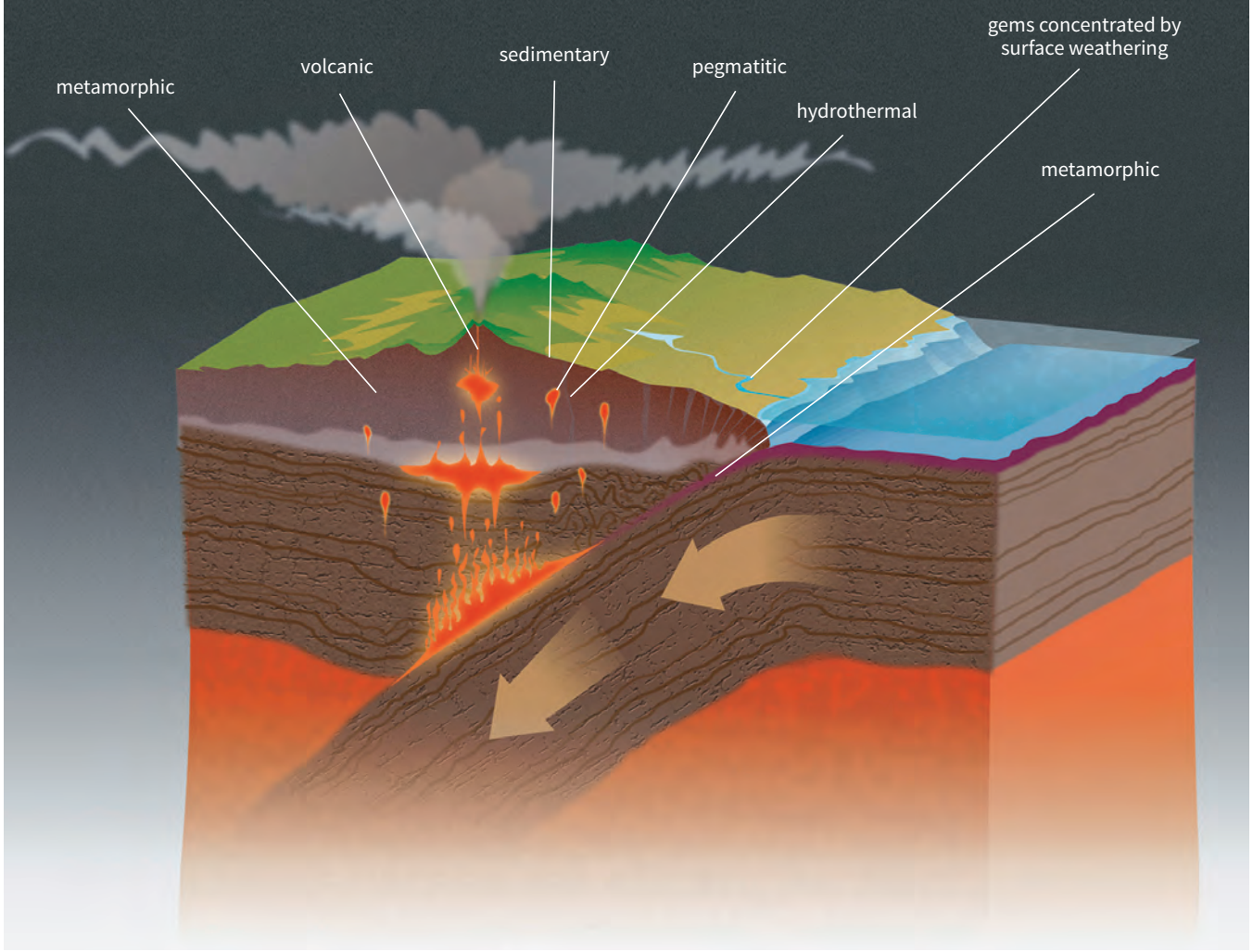
Most colored stones are formed in the earth's continental crust. The continental crust is made mostly of granite, while oceanic crust is basalt. The crust is a dynamic mosaic of moving plates, constantly in motion. The motion takes place imperceptibly over many millions of years.

When continental plates collide, or ocean crust descends under the continental edge, mountains are built. Large bodies of rock melt, granite forms, and heat and pressure transform existing minerals into new ones. Many important gems—including ruby, sapphire, and garnet—can form at this time.

Molten rock from the mantle taps deep layers in the crust and brings existing gems to the surface. Large bodies of granite or other igneous rock provide heat for metamorphism and inject pegmatites into fractures in the rock. Later, the same granites release hydrothermal fluids that form new mineral veins. Topaz and some emerald deposits might form under these conditions.

As fast as mountain ranges rise, frost shatters the high peaks and exposes gem-bearing rocks. High rainfall carries the debris away, and concentrates the hard, chemically stable gems in the river and stream gravel.

This dynamic process takes place over many millions of years to continually recycle and restructure the earth's crust.

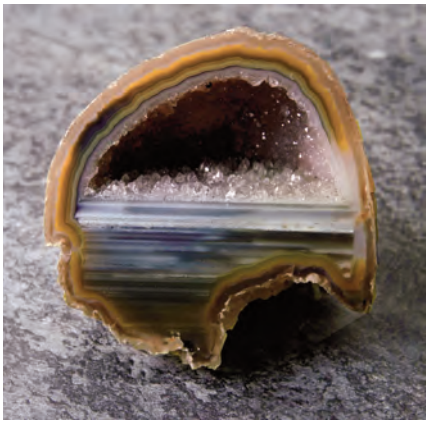


Peter Johnston/GIA

Geode Formation

When magma is brought rapidly to the surface, the reduced pressure causes gasses in the hot rock to expand and form cavities within the solidifying rock. Later, mineral-laden water moving through the rock might deposit new minerals in these cavities to form *geodes*.

Geodes commonly contain concentric layers of agate, a form of quartz made up of tiny crystals. If the agate doesn't completely fill the geode, a crystal-lined cavity might form at the center. Usually, the crystals are colorless quartz, but some geodes do contain gem-quality amethyst.



Eric Welch/GIA

Geodes start out as cavities in igneous rock. As mineral-rich water moves through the rock, it deposits new minerals. Geodes often consist of bands of agate and a central cavity lined with quartz crystals.

Geode—A spherical, often hollow, mineral-lined cavity in rock.

Mining and Recovery

- What factors affect mine economics?
- How do prospectors decide where to look for new gem sources?
- Which gem deposits are the most economic to mine?

Colored stone mining operations can be primitive and hazardous. They are often located in remote mountainous areas, where transport to and from the mining site can be extremely difficult. Public resources such as bridges, roads, and water supply can all be primitive or even lacking. And even the most basic mining operations are affected by factors such as politics, accessibility, climate, available labor, and demand.

Andrew Lucas/GIA

This open-pit sapphire mining operation in Sri Lanka is located near roads and a large, well established trading center. This makes access relatively easy. It is also a legal operation on privately owned land that meets all environmental regulations so there is no fear of government intrusion.

Andrew Lucas/GIA

Most gemstone miners in Sri Lanka work in open pits, using methods that have remained unchanged for centuries. Until fairly recently, government legislation in Sri Lanka prevented virtually all mechanized mining.

Andrew Lucas/GIA

This simple pit-mining operation in Cambodia is in the jungle near Pailin. It's in an area threatened by incurable malaria and unclear legality. These conditions and others make mining difficult.

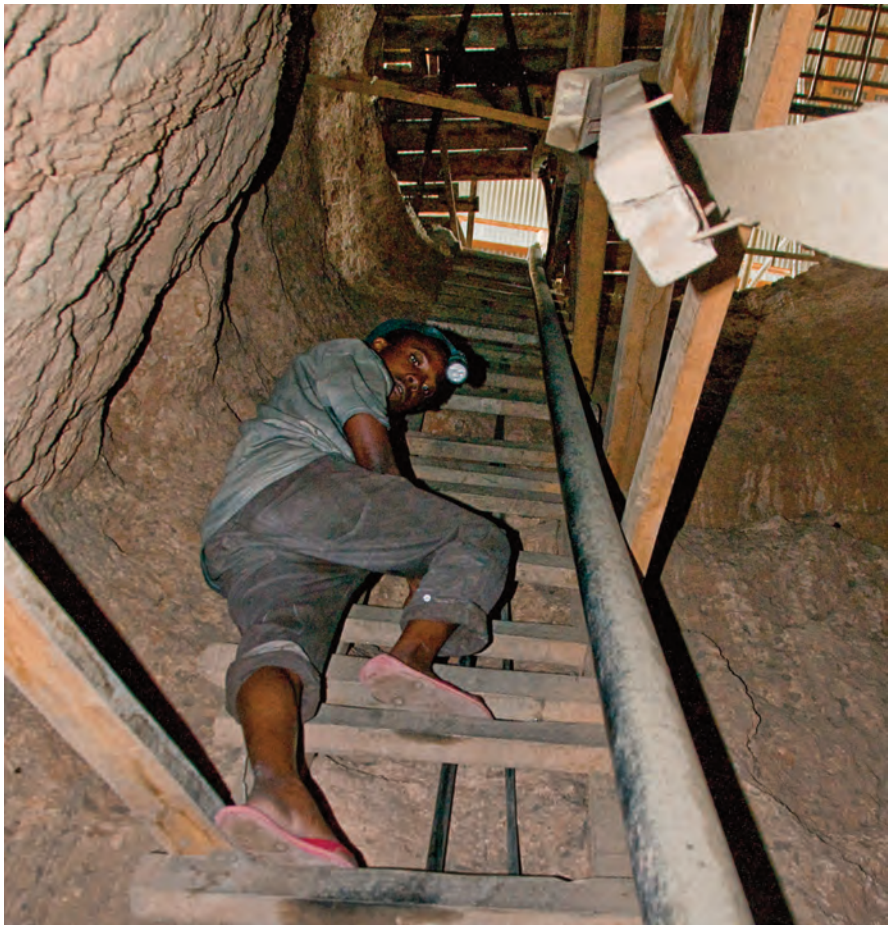
Brendan Laurs/GIA

Many people who see beautiful gems in jewelers' showcases don't realize the effort and expense required to bring them to the surface.

Mining is about making money. The same rules of supply and demand that govern any product apply to gems. Consumer desire for the gem and sufficient quantities to guarantee supply—along with the all-important blend of beauty, rarity, and durability—work together to assure a gem's success in the marketplace.

Timing is important, too. It's not economic to begin mining a new deposit of commercial-grade sapphire if the market is already saturated with similar goods. The product of a mine has to be desirable. Promotion can also make a difference in a gem's desirability.

Tanzanite provides a good illustration of the many factors that influence a gem's place in the market. It's an attractive gem that appeared on the market in the 1960s. Jewelers began to promote it, and consumer interest rose. But supplies of tanzanite are subject to dramatic fluctuations because it comes from a single commercial source. At various times since the gem's introduction, its source mine has experienced local labor problems as well as natural disasters. These problems have continued, causing fluctuations in the supply and price of tanzanite.



Brendan Laurs/GIA

Tanzanite supplies are limited by the primitive and often dangerous conditions at many mines.

The Economics of Gem Mining

Jewelry outlets are at the end of a long, often complex, supply chain that stretches back to remote mines scattered around the world. Gem resources can be mined by small-scale methods over centuries, or depleted in a few short decades using intensive modern mining.

Many of the mining operations that supply us with gems like tanzanite, ruby, or emerald are only profitable because their labor costs are so low. This is because the countries they're located in have generally low standards of living. But even if mining costs are relatively low, each set of hands a stone passes through adds to its value.

Artisanal miner—An independent gem or mineral prospector who typically uses small-scale, non-mechanized recovery methods.

It's estimated that the majority of colored gems in circulation today—perhaps as much as 80 percent—are supplied by *artisanal miners*. These independent, small-scale miners use mostly non-mechanized gem-recovery methods.

To bring a rough tanzanite to the surface, an artisanal miner in East Africa risks his life in a makeshift mine deep underground for very little pay. The rough gem typically passes through the hands of local dealers before it's sold to a buyer who represents an international gemstone cutter. The rough is exported and then—like almost all tanzanite—enhanced by heat treatment. If it's fine enough, it's faceted by skilled European lapidaries. In New York, a discerning jeweler selects the stone from a tray of other fine gems. Finally, the fine-quality tanzanite is set in a custom designed, handmade mounting and sold at a premium.

In contrast to small-scale artisanal operations, in recent years larger corporations have become involved in colored stone mining. An example is Gemfields, a multinational British corporation that operates Mozambique's Montepuez ruby deposit in partnership with a local company. The operation, known as Montepuez Ruby Mining Company (MRM), brings a much more systematic and mechanized approach to evaluating and mining a gem deposit, then marketing its production. Gemfields also operates Zambia's Kagem emerald mine in collaboration with the Zambian government.

Eric Welch/GIA, courtesy Piteiras Mine

In contrast to individual, primitive endeavors, the underground emerald mine in Minas Gerais, Brazil, operates with modern efficiency.

Robert Kane/GIA

Crouched in a small pit, a worker in a mine near Chanthaburi, in eastern Thailand, searches for a few rough sapphires. In a good week this mine produces a handful of rough.

Vincent Pardieu/GIA, courtesy Gemfields

Private security guards at the modern Gemfields ruby mine in Mozambique stand guard to prevent theft from workers and outside intruders.

In an effort to exert greater control over the supply chain, the company sells its rough gems through a well-organized auction system. They also often cut a portion of their own production and might even produce and sell jewelry containing the gems they mine and fashion.

Although large operations do exist, artisanal miners still operate the majority of gem deposits. This is either because the geology is not suitable for mechanized mining or because the mines are simply too small to be economically viable using modern methods.

No matter how the gem is brought to market, the value of the end product—after cutting, jewelry manufacturing, and retailing—has increased many times over the cost of the original rough stone.

Factors That Affect Gem Mining Costs

Gems are concentrated and easily concealed forms of wealth. As a result, all gem-mining operations cope with a certain level of loss. Theft of production by workers without much to lose can be rampant. Nevertheless many of these operations remain viable precisely because of low labor costs. If the same deposit were located in a country with a higher-wage economy, the costs of mining would probably exceed potential profits.

Changes in the political climate of a producer country can shut down mining operations overnight, with drastic consequences to gem supplies. Burmese ruby became much scarcer in the 1960s following a military coup. Not only did Burma's new leaders change the country's name to Myanmar, they also clamped down on all gem mining. This caused another country—Thailand—to regain its status as the world's chief ruby supplier.

Vincent Pardieu/GIA

Unlicensed miners in Mozambique gather near their primitive mining pit.

Andrew Lucas/GIA

These miners in Myanmar haul up piles of marble rocks for crushing, in hopes of finding valuable gems.

When a rich new gem deposit is discovered, there's often a frantic rush to exploit it. When a new deposit of good-quality sapphire was discovered in Madagascar in the mid-1990s, miners abandoned their activities elsewhere on the island to rush to the new strike. Established emerald mines in other parts of the country lost workers, and emerald production suffered.

Rate of production is also important. Government regulation kept gem mining small in Sri Lanka. In the 1970s and 1980s, Thailand's government permitted intensive mechanized mining of ruby deposits in the eastern part of the country. In a few short decades gem corundum was all gone.

Gary Bowersox

The emeralds of Afghanistan's Panjshir Valley come from a deposit high in the Himalayas. The jagged peaks of the Hindu Kush illustrate the physical challenges involved in mining such a remote location.

The environment suffered from the intense—and abusive—mining practices, and a limited number of individuals became enormously wealthy.

The climate of a mining area can be savage and uncooperative. Mining can be impossible for all but a few short months of the year in high mountain sites. A classic example is the legendary Kashmir sapphire mine high in the Himalayas. It's located in the disputed border region between India and Pakistan. All of the difficulties that beset gem mining come together with this mine: difficult politics, inaccessibility, difficulty in getting a labor force, plus harsh climate and environment.

Before mining begins, prospectors must decide what type of deposit they're dealing with. Is the rock so hard that getting the gems out is difficult, or are the gems easily extracted? Are the gems concentrated in river gravel or scattered through the source rock?

Deposit type also determines mining methods. You don't need drilling and blasting equipment to mine river gravel, and the equipment and techniques used to mine river deposits are useless for mining solid uneroded rock.

KEY CONCEPTS

Mining economics are affected by demand, political climate, labor costs, environment, accessibility, type of deposit, and mining methods.

KEY CONCEPTS

An understanding of gemstone formation helps prospectors pick the right places to look for gems.

Finding Gems

Understanding the way gems form helps prospectors search for likely source areas. Earlier in this assignment you saw that the process of plate tectonics raises mountains and breaks down large areas of the earth's crust. Many of the world's best gem resources lie within these mountain belts.

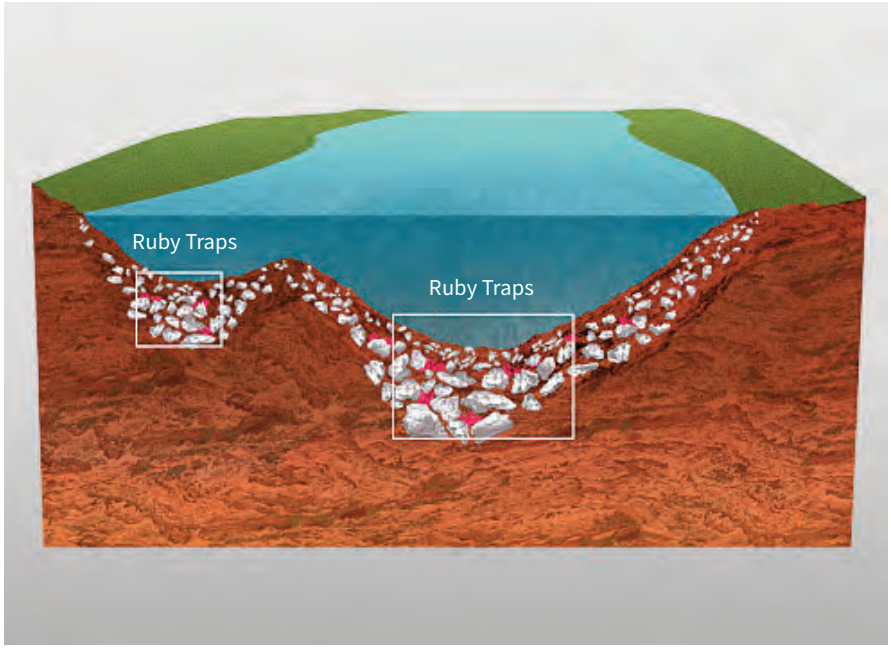
One time-honored prospecting method is to sample mineral deposits in streambeds and follow the stream back upriver to the source rocks. Rocks degrade rapidly in tropical climates to produce thick soils. Lush vegetation doesn't just complicate finding the original gem-bearing rock, it limits access and makes map reading very difficult.

Alan Jobbins

The old methods are still effective when it comes to gemstone mining and prospecting. In Myanmar's Mogok region, a miner examines the contents of an upturned washing basket at the edge of a stream. A circular washing action concentrates heavier gem minerals in the center of the basket and lighter waste rock at the edge.

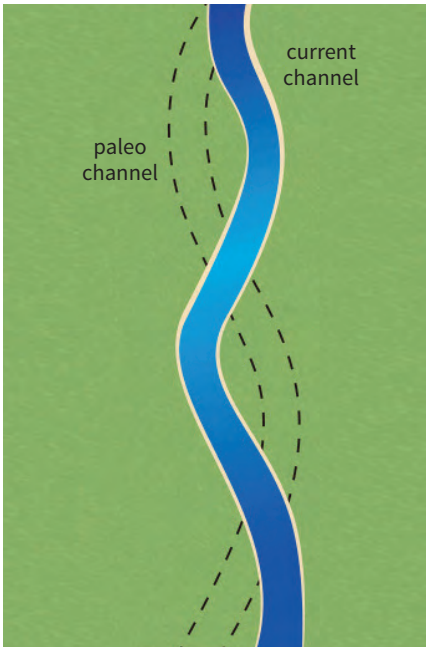
Andrew Lucas/GIA

Most colored gem miners—like this independent emerald miner in Minas Gerais, Brazil—use traditional methods and simple tools.



Peter Johnston/GIA

Rubies tend to concentrate at the bottom of depressions that form along former river bends. Large gravels also help to trap the rubies.



Peter Johnston/GIA

As ancient waterways changed direction over millions of years, they left dry and buried traces of those direction changes in so-called paleochannels.

Prospectors look to the world's mountainous areas for new sources of fine ruby, sapphire, and emerald. But existing mountain chains are not the only gem sources. Many ancient mountain chains have been reduced to rubble by the forces of erosion, and their sediments spread over vast areas.

The mountain belt that runs through the eastern African countries of Mozambique, Kenya, and Tanzania is an example of an ancient mountain range with huge gem deposits. And millions of years of erosion of that mountain chain might have produced the abundant sapphire deposits of Madagascar.

In Mozambique, MRM began prospecting by following existing rivers, just as artisanal miners do. However, they also looked for underlying traces of ancient waterways—now dried up and buried—that changed direction over millions of years. Geologists call them paleochannels. They can contain concentrations of rubies that, because of their high specific gravity, collect in depressions the miners call ruby traps.

In open-pit operations, excavators remove the *overburden*—the soil or sediment that covers the deposit. The overburden must be removed in order to reach the gem-bearing gravels and begin production. The gravels are then loaded into trucks and transported to the washing plant.

Overburden—The material covering a gem deposit that must be removed before production can begin.

The overburden is relatively shallow, making the payoff high in comparison to the mining effort. MRM uses an auger drill—a rotating spiral screw driven into the ground—to trap the loose gravel and soil and bring it back up through the drill-hole. This type of drilling is ideal for surveying softened ground and weak weathered rocks.

Robert Kane/GIA

Lin Yaung Chi in Mogok is a primary or "hard rock" mine. The operators use drilling and blasting equipment to release corundum from the rock.

Andrew Lucas/GIA, courtesy Belmont Mine

The Belmont emerald mine is a modern, large-scale operation where hydraulic shovels load ore into giant trucks for transport to the processing facility.

Primary Deposits

Primary deposit—Gems found in the rocks that they formed in.

Colombian emerald, Paraíba tourmaline, and tanzanite are mined directly from the rock they formed in. When gems are mined directly from the original rock, the deposit is described as a *primary deposit*. Some gems, like opal and emerald, have to be mined directly from the source rock because they are too fragile to survive water transport.

In primary deposits (also known as "hard rock" deposits), the gem material is extracted by drilling and blasting. Expensive tunneling might also be used to follow the deposit underground.

As you learned earlier in this assignment, pegmatites are important primary sources. Gem-bearing pegmatites can be very profitable because they contain large, fine gem crystals in concentrated pockets. The tourmaline mines of San Diego County, California, US, are a good example of a pegmatite source.

Andrew Lucas/GIA, courtesy Belmont Mine

Vast underground tunnels at Belmont lead to the mine's primary sources.

Most primary colored stone deposits are small, especially when compared to the world's giant diamond mines. The industrial methods used by diamond miners are less often applied to colored stones.

Brazil's Belmont emerald mine is an example of a modern, large-scale, mechanized operation with underground mining of a primary deposit. Its operators invested in comprehensive geological surveys to outline the extent of the emerald-bearing schist and a state-of-the-art recovery plant to efficiently process production.

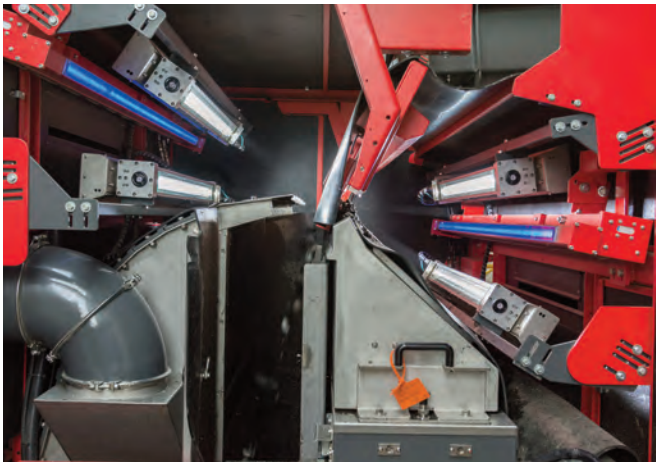
Drill cores are essential to mine planning. They help miners plan the mine's structure because they show the strengths and weaknesses of different rock layers and indicate which layers are capable of supporting underground tunnels. The drill cores also help miners understand the underlying geology. To determine the extent of the emerald-bearing ore, Belmont miners have drilled more than 15 km (almost 10 miles) of cores. When the cores contain schist, the mine geologist sends samples for chemical analysis to assess the potential for emerald mineralization. The rocks' chemistry can tell them if there might be high-quality, intense green emeralds, or lower-quality, lighter-colored stones.

The mine has a modern processing plant that uses a series of crushers to break down the ore, followed by washing with high-pressure water jets to clean the concentrate. This vital washing step allows the mine's sophisticated optical sorting machines to detect and separate the emeralds from the ore.

One of the main concerns in any mining operation is water contamination. Water is necessary for gemstone mining, especially during the processing of the ore and recovery of the gemstones. Once mining is complete, Belmont miners make efforts to restore the land to its former, pristine state. They use a seven-pond filtration system to purify the water used during mining and processing. Besides water reclamation, the mine's operators refill pits and other mined areas and reforest those areas to restore the environment to its pre-mining condition.

Andrew Lucas/GIA, courtesy Belmont Mine

In Belmont's modern washing and recovery plant, screens separate the ore by size for further analysis.



AndrewLucas/GIA, courtesy Belmont Mine

As the ore passes through Belmont's optical sorter, it automatically detects the emerald rough and separates it out with a blast of air.

Alan Jobbins

This handful of tumbled red and fancy-color corundum rough from Vietnam's Luc Yen Valley proves that even hard, tough gems like corundum can be worn to featureless pebbles after enough time and exposure.

Secondary Deposits

Secondary deposit—Gems found away from their primary source.

As you've seen, primary sources can be important, but many profitable colored stone sources are found in *secondary deposits*. These occur when gems erode from the rock they formed in and accumulate in river gravel.

With secondary deposits, nature has done most of the miner's work. The erosion process wears away huge quantities of rock and leaves gem materials concentrated in commercially important deposits. In many cases, thousands of tons of eroded rock might yield only a few ounces of gem material.

Secondary sources are usually mined first. They're usually more profitable than primary sources because the gem materials are more concentrated and easier to access. And they contain a higher percentage of high-quality material than primary deposits. Their better-quality, more concentrated material provides miners with a quicker return. And mining them doesn't usually require costly equipment.

Most primary deposits have secondary deposits associated with them. Examples are the pegmatites of Minas Gerais, Brazil, and the jadeite deposits of Tawmaw, Myanmar, where alluvial jadeite boulders are found in the gravel of the Uru River.

KEY CONCEPTS

Thousands of tons of eroded rock might yield only a few ounces of gem material.

Secondary deposits are easier to work than primary ones and might contain greater concentrations of gems.

Vincent Pardieu/GIA

This independent Cambodian miner scoops a shovelful of alluvial gravel into a washing screen. Most of the gem materials he finds will be corundum because it's tough enough to survive the tumbling action of the river and heavy enough to be concentrated in the gravel.

Vincent Pardieu/GIA

This miner near Pailin, Cambodia, is screening river gravel in search of rounded, high-clarity corundum crystals. They would be similar in shape to the water-worn pebbles all around him, so a keen eye is essential.

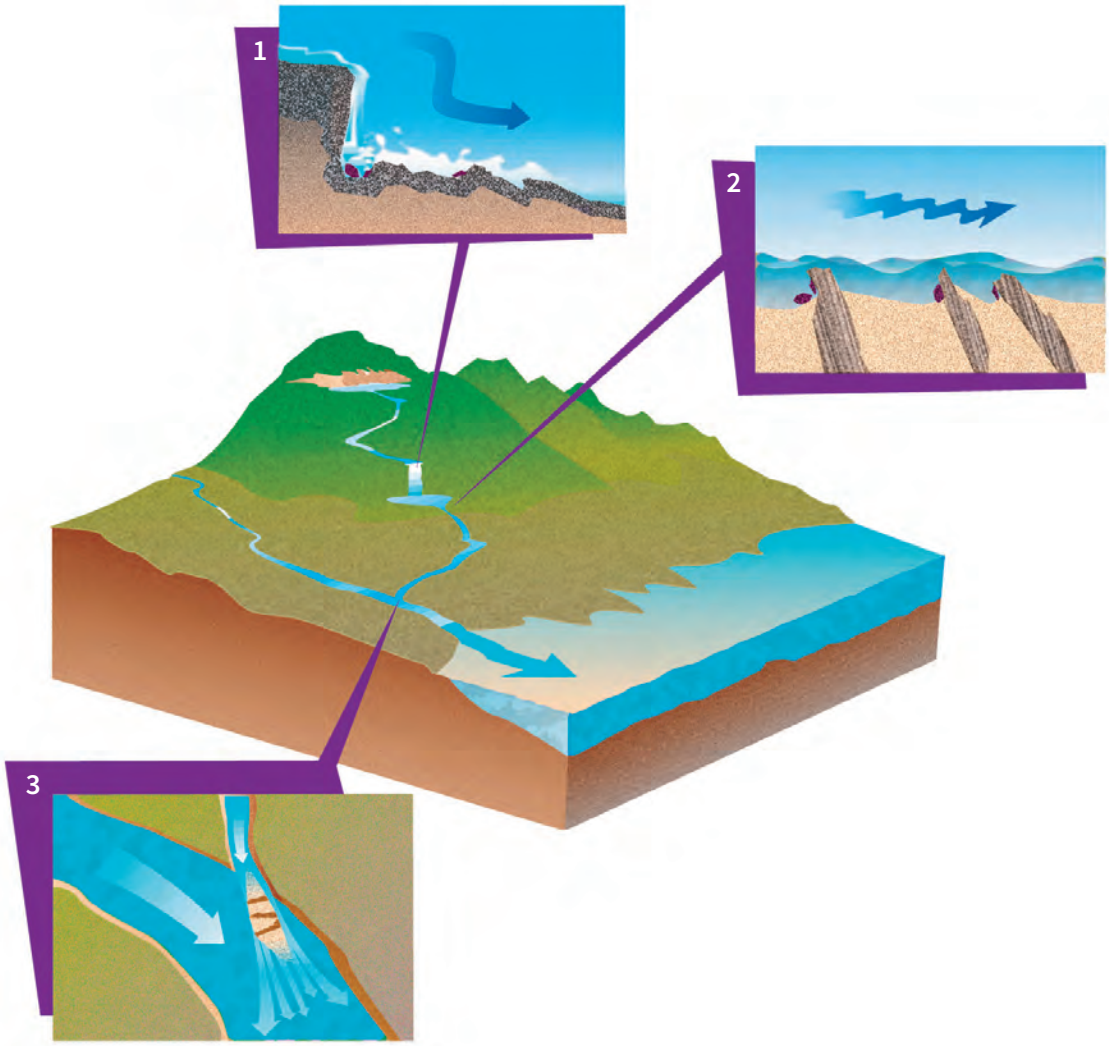
Nature's Gem Toughness Test

Gems are tough. Physical properties like chemical stability, hardness, toughness, and cleavage determine a gem's ability to withstand weathering and transport in water. Secondary deposits are testing grounds for gem crystals.

Poorer-quality fractured gems are broken up during weathering and transportation. This gives secondary sources a high proportion of better-quality gems. Depending on the distance it travels, a gem might have much of its crystal shape intact, or it might be rounded to a smooth pebble.

KEY CONCEPTS

Only the toughest gems survive to become part of secondary deposits.



Peter Johnston/GIA

A fairly simple process brings gems to secondary deposits. Erosion exposes a gem-bearing outcrop high in the mountains and carries the materials away. Placers—economic concentrations of gem materials—can form at the base of a waterfall or in potholes in the riverbed (1), behind bands of more resistant rock that stand above the riverbed and act as traps (2), or anywhere a stream slows down (3).

Heavy minerals—Minerals dense enough to become concentrated and separated from lighter ones by the action of surface water.

Gems carried in water travel shorter distances and sink faster than lighter minerals eroded at the same time. The term *heavy minerals* is often used to describe gems and other dense materials that can be separated from lighter minerals by flowing water.

Gems and other heavy minerals can concentrate where rivers or streams are slow enough to allow them to drop to the riverbed. This can happen where the current slows down, such as where a smaller tributary enters a larger river, or on the outside of a bend in the river. It can also happen when the flowing water encounters an obstacle in the streambed, such as a band of more resistant rock or a pothole. A plunge hole at the base of a waterfall can also catch heavy materials.

Eluvial and Alluvial Deposits

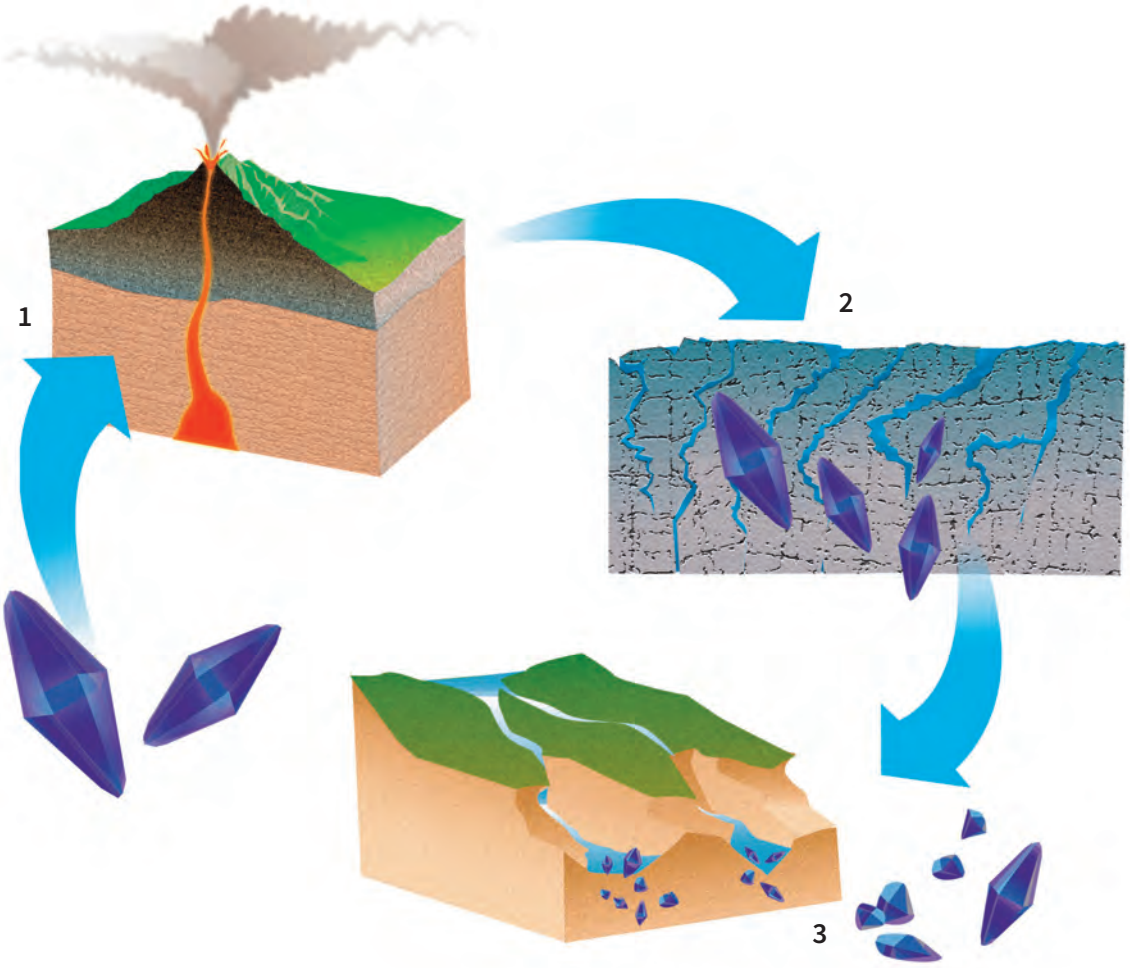
Two main types of secondary deposits can form when gem-bearing rock is broken down: *eluvial deposits* and *alluvial deposits*.

In both types, the gem material becomes more concentrated than in the source rock. As weathering breaks down the surrounding rock, the hard, resistant gems become concentrated in ever-smaller volumes of debris. In eluvial deposits, the gems mostly stay immediately around the source, making the source rocks relatively easy to find.

In alluvial deposits, the gems don't stay close to the source rock, but are removed by fast-moving rivers and streams. Fast-flowing water is highly effective at sorting gems from weathered rock and other lighter minerals. Unlike eluvial gems, alluvial gems can be many miles away from their original source rocks.

Eluvial deposit—A deposit where gems are eroded from the source rock but remain in place close to the source.

Alluvial deposit—A deposit where gems are eroded from their source rock, then transported away from the source and further concentrated.



Peter Johnston/GIA

Gems can end up far away from their formation locations. Volcanic activity carries gems to the surface from deep in the crust. The gems within the volcanic rock that brought them to the surface create a primary deposit (1). Weathering decomposes the volcanic rock. As the rock decomposes and washes away, the gems remain in the original site. This creates an eluvial deposit (2). If water carries the gems away from the original site and deposits them elsewhere, the new deposit is alluvial (3).

Alluvial deposits can be found downstream from mountainous areas where rainfall is high, and gravity helps transport and sort material weathered from gem-bearing rocks. Ancient river gravel is as plentiful a source as existing rivers.

Gem minerals that are commonly found in alluvial deposits include ruby and sapphire, jade, spinel, tourmaline, aquamarine, and chrysoberyl. Emeralds are too delicate to stand much abrasion and are not found in alluvial deposits, but they can be found in eluvial deposits.

Placer—Workable alluvial deposit of gem minerals with economic potential.

Although prospectors can uncover some alluvial gem concentrations by examining the heavy mineral contents of stream deposits, many gems are found while prospecting for other minerals and metals. Alluvial deposits with economic potential are called *placers* by gem miners. Placers are workable deposits of gem minerals with commercial potential, concentrated by erosion and the action of surface water.

Good examples of gem placers are found in Sri Lanka, or in the Umba River Valley in Tanzania. Rocks break down most quickly in tropical climates with high rainfall. Because of the rapid pace of erosion, fast-flowing streams carry heavy loads of sediment—including gems—and quickly build extensive alluvial deposits.

An alluvial deposit frequently represents the end result of the earth's natural gem formation processes. For many colored stones, it also marks the beginning of another journey: the journey from source to market, during which gems are mined, sorted, and traded across continents.

Robert Kammerling/GIA

Rough gem dealers exhibit graded piles of rough to potential buyers in the ruby trading center of Luc Yen, Vietnam. From there, most of the gems go to Bangkok and Chantaburi, Thailand, for treatment and cutting.

Robert Weldon/GIA, courtesy Lewis Allen

It takes time and skilled craftsmanship to cut, match, and set emeralds of this quality into a mounting worthy of their beauty. This course will help you assess the quality of colored stones, from the inexpensive basics of mass-market jewelry, to the fine stones that grace the most prestigious pieces.

Even before it's cut and polished, a rough gem might pass through many different dealers. At some point, the gem is faceted on a cutter's wheel—probably in one of the world's major cutting centers. Once it's faceted, the gem begins what's possibly the final stage of its journey. It's graded, sorted, and traded again. Finally, it's selected and set in a piece of jewelry. You'll learn about the many stages in a gem's progress through the colored stone market later in this course. Meanwhile, the next assignment will introduce the physical properties that make individual gems the special treasures that they are.

Alluvial Mining at Luc Yen

The principles of alluvial mining are the same the world over. Only the sophistication of the machinery differs from place to place. Alluvial mining techniques duplicate the natural process of erosion, using water and gravity to separate gem minerals from lighter rock debris.

A new ruby and fancy sapphire source near Luc Yen in northern Vietnam made the headlines in the end of the 1980s and early 1990s. Although mechanized alluvial mining was short-lived, these photographs show the mining process.

Alan Jobbins

1. A Major Source of Ruby and Sapphire

High in the mountains of northern Vietnam, intense weathering released ruby from primary sources in marble, and gems became concentrated in alluvial deposits in the valleys below.

Alan Jobbins

2. The Rough Material

These big crystals sparked gem fever. Miners stampeded to Luc Yen by the thousands, and unofficial mining was rampant. The Vietnamese government declared a moratorium on unauthorized small-scale gem mining. Soon after that, mechanized mining was organized as a joint venture between the Vietnamese state-run gem corporation and a Thai mining company.

Alan Jobbins

3. Liquefying the Gem Gravel

After the gem gravel is located, the useless waste material (overburden) above it must be removed. High-pressure hoses liquefy the gravel so it can be pumped to a trommel for separation.

4. Starting the Separation Process

A trommel is a rotating screen used to sort out oversize material from the gem-bearing mud before it goes on to the next stage of sorting. Large rocks are ejected, and only sizes between 0.69 and 0.79 in. (1.75 and 2.00 cm) in size go on to the next stage of separation.

Alan Jobbins

5. Heavy Mineral Separation

From the trommel, the sorted gravel is carried downhill through a series of screens of different mesh sizes. They sort the gravel further by using the high specific gravity of the corundum. Lighter minerals remain in suspension and pass over the screens with the wastewater, while the heavier minerals drop through the screen mesh and are collected. At the end of the day the water is turned off and workers remove the gem concentrate and sort it by hand.

Alan Jobbins

6. First Handsorting

The sorters reject some material, like the non-gem corundum and other heavy minerals such as the black spinel found in this scoop.

Alan Jobbins

7. Sorting Rough Ruby

The rough ruby that's left is sorted on tables.

Shane McClure/GIA, courtesy Gold Rush

8. The Finished Product

The quality of ruby and pink sapphire from Luc Yen was good, but the stones were on the market for only a short time in the early 1990s. Management problems, politics, and infrastructure problems have frustrated mechanized mining at Luc Yen. It is believed that the area has reverted to small-scale independent mining. Many people believe that the area will again be a significant producer once the political problems are resolved.

KEY CONCEPTS

Rocks are the raw materials of gemstone formation.

Most colored stones form in the earth's continental crust.

Geological conditions during mountain building are favorable for gem formation.

In most igneous rocks, large crystals indicate slow cooling, while small crystals indicate rapid cooling.

Some types of volcanic rock can transport existing gems from deep in the crust to the earth's surface.

Some of the largest and most perfect gem crystals come from pegmatites.

Superheated, pressurized water can transfer elements in solution and redeposit them in veins to form gems.

Mining economics are affected by demand, political climate, labor costs, environment, accessibility, type of deposit, and mining methods.

An understanding of gemstone formation helps prospectors pick the right places to look for gems.

Thousands of tons of eroded rock might yield only a few ounces of gem material.

Secondary deposits are easier to work than primary ones and might contain greater concentrations of gems.

Only the toughest gems survive to become part of secondary deposits.

Key Terms

Alluvial deposit—A deposit where gems are eroded from their source rock, then transported away from the source and further concentrated.

Artisanal miner—An independent gem or mineral prospector who typically uses small-scale, non-mechanized recovery methods.

Contact metamorphism—Localized changes caused by an igneous intrusion that takes place where the magma meets the surrounding rock.

Core—The earth's innermost layer.

Crust—The surface and outermost layer of the earth.

Eluvial deposit—A deposit where gems are eroded from the source rock but remain in place close to the source.

Erosion—The wearing away and transport of rock materials by natural forces.

Geode—A spherical, often hollow, mineral-lined cavity in rock.

Heavy minerals—Minerals dense enough to become concentrated and separated from lighter ones by the action of surface water.

Hydrothermal fluid—Hot, high-pressure solution that can dissolve, transport, and deposit minerals from one place to another.

Igneous rock—Rock formed by the crystallization of molten material.

Intrusion—Large mass of igneous rock that crystallizes underground without reaching the surface.

Magma—General term for any molten rock.

Mantle—A layer between the earth's crust and its core.

Mantle convection—Circulation in the mantle that drives the movement of the earth's plates.

Metamorphic rock—A category of rocks that have been altered by heat and pressure.

Metasomatism—A type of metamorphism where chemical changes in the minerals and rocks result from the introduction of material from external sources, often as hydrothermal solutions.

Orogenic belt—A long, widespread area in the earth's crust where tectonic events cause major structural changes, often forming mountain ranges.

Overburden—The material covering a gem deposit that must be removed before production can begin.

Pegmatite—An igneous rock typically formed from cooling, once-molten granite that follows fractures in its surrounding rock.

Placer—Workable alluvial deposit of gem minerals with economic potential.

Plate—A section of the earth's rigid outer crust.

Plate tectonics—Study of the formation, structure, and movement of the plates of the earth's crust.

Pneumatolysis—Crystallization of minerals from a gas.

Primary deposit—Gems found in the rocks that they formed in.

Regional metamorphism—Changes in rock type and minerals over a wide area, caused by heat and pressure of large-scale geological events.

Rock cycle—A constant formation and recycling process that creates new rock from old.

Secondary deposit—Gems found away from their primary source.

Sedimentary rock—Rock produced from the eroded and weathered remains of existing rocks.

Subduction—A process that occurs when two of the earth's plates collide, forcing one under the other.

Vein—A mineral deposit that occupies an existing fissure or fracture in the rock.

Volcanic—Pertaining to igneous activity at the earth's surface, where magma erupts through a volcano or fissure.

Xenocryst—A "foreign crystal" that forms in unrelated rocks and is brought to the surface as a passenger in magma.

Questions for Review

- What causes the movement of the earth's crust?
- What geological conditions are best for gem formation?
- What are the major rock formation processes?
- Which gemstones are associated with igneous rocks?
- What crucial role does superheated water play in gem formation?
- Which gems are associated with metamorphic rocks?
- Which gem deposits are formed by sedimentary processes?
- What factors affect mine economics?
- How do prospectors decide where to look for new gem sources?
- Which gem deposits are the most economic to mine?

Gems and Their Physical Properties

3

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Welcome to *Colored Stones* Assignment 3. With the knowledge you gain from this assignment, you'll be able to:

- Describe the growth of a gem crystal.
- Explain how and when inclusions become part of a gem.
- Recognize the outward signs of a gem's inner structure.
- Understand the relationship between a gem's structure and its finished shape.
- Relate a gem's physical properties to its usefulness in jewelry.

Jeffrey Scovil, courtesy Keith Proctor Collection

The sharp angles and flat faces of this red spinel crystal reflect the order of its internal structure.

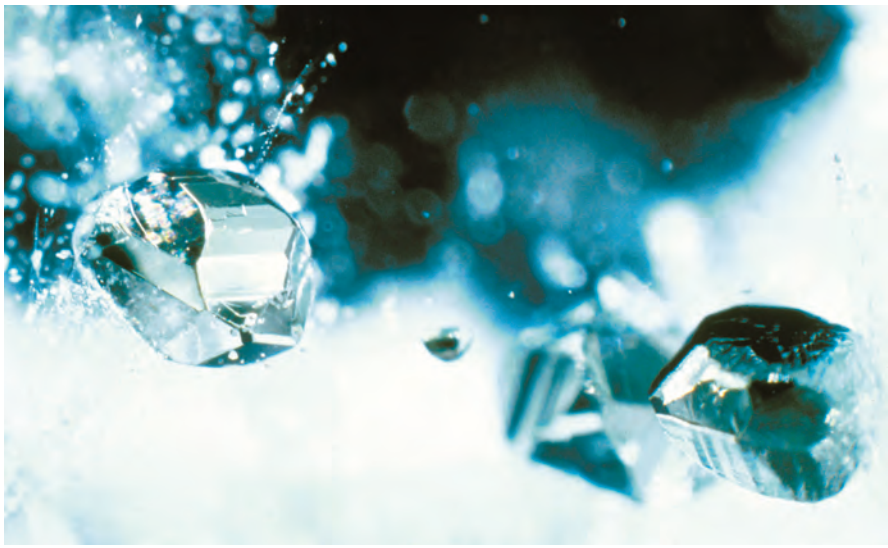
Gems and Their Physical Properties

Few things in nature compare with the beauty of a well-formed crystal, with its miniature architecture of sharp angles and precise geometry. Even when they're concealed behind a fashioned gem's exterior of flat facets or smooth curves, the original rough crystal's structure and chemistry remain.

A gem's crystal structure and chemical composition determine all of its strengths and weaknesses: its color, its hardness or softness, its weight, how it reacts with light, how well it resists wear, and even the way it reacts to treatment. And the size and shape of a rough crystal dictate the size and shape of the faceted stone that can be cut from it.

Assignment 2 introduced you to the geological processes that bring the right rocks together at the right time and under the right conditions for gem growth. You learned how a growing crystal interacts dynamically with its environment.

Unit cell—The smallest group of atoms with both the characteristic chemical composition and crystal structure of a mineral.



John Koivula/GIA

Crystals compete for essential elements as they grow. These pyrite crystals grew at the same time as the surrounding quartz crystal. They became inclusions in the quartz when the faster-growing quartz surrounded them and arrested their growth.

Robert Weldon/GIA, courtesy John Koivula

Sometimes, inclusions provide a distinctive appearance that adds to a gem's value. This quartz cabochon, with its radiating rutile needles, makes a dramatic pendant.

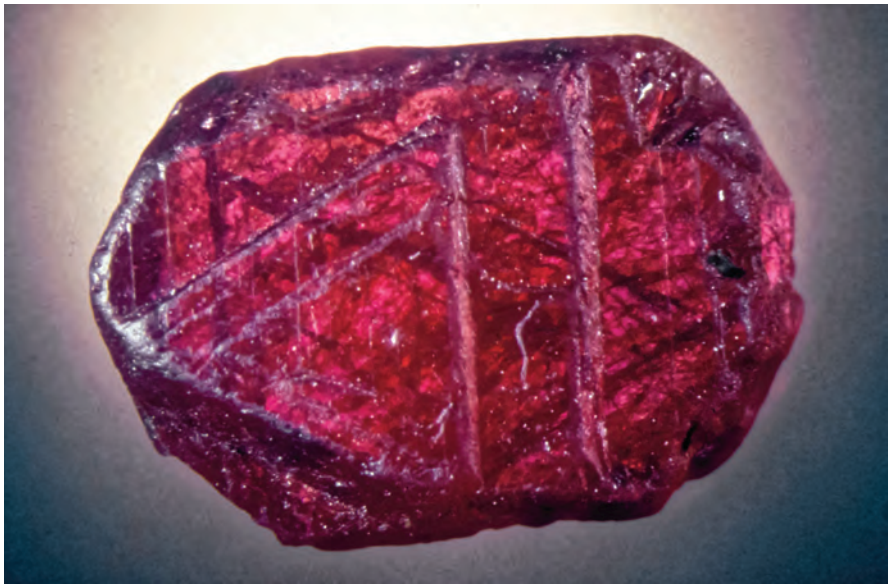
Available chemical elements, space for growth, and cooling time all directly affect the external shape, size, and color of a gem crystal. As a result, they also have a direct impact on the gem's value. Disturbances in growth that lead to such things as mineral inclusions and distorted internal structure—which you'll learn about in this assignment—also have an impact on the finished stone's appearance.

Understanding colored stones' physical properties—those properties that have to do with weight and durability—will help you understand their differences in rarity and relative values. This is valuable knowledge for colored stone buyers, store managers, dealers, and others who want to enhance their professional standing in the gem world. The knowledge you gain here will serve as a basis for understanding individual gemstones as you move through this course. It will also help you apply your increasing knowledge in the colored stone marketplace.

How Crystals Grow

- How does a rough crystal get its start?
- How do inclusions and trace elements become part of a gem?
- What features can help you recognize different rough gemstones?
- How does crystal shape affect the way a stone is cut?

The well-formed faces on a glittering quartz crystal are an outward expression of its inner order. They reflect the internal repetition of tiny identical geometric building blocks. Each building block is called a *unit cell*. The unit cell is the mineral's "signature"—its basic identity. It consists of the smallest group of atoms with the same chemical composition and crystal structure as the gem material as a whole.



John Koivula/GIA, courtesy John Fuhrbah

Alan Jobbins

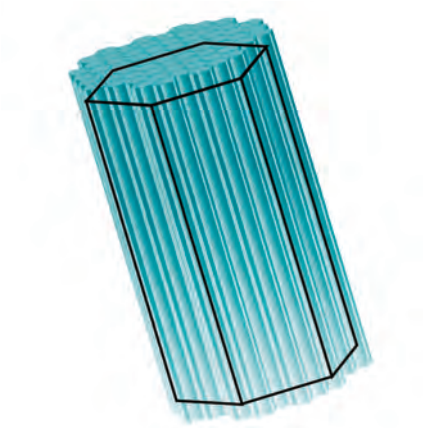
The shape of a rough crystal dictates the shape and size of the finished gem. Because ruby rough is so expensive, a cutter would probably fashion a single shallow stone from this flattened crystal (left). It would result in a gem very similar to the 5x4-mm Thai ruby (right). To produce the largest stone possible, the cutter was forced to cut a very shallow gem. It's so shallow that the text is visible through it.

Kari A. Kinnunen

These rectangular etch marks are on one of a beryl crystal's six vertical faces. They signal the crystal's microscopic internal symmetry. (8X)

Jeffrey Scovil, courtesy Wayne Thompson Minerals

Topped by a flat face, this six-sided Brazilian aquamarine crystal measures 28 cm. The broken base shows where the crystal was attached to the pegmatite rock as it grew.



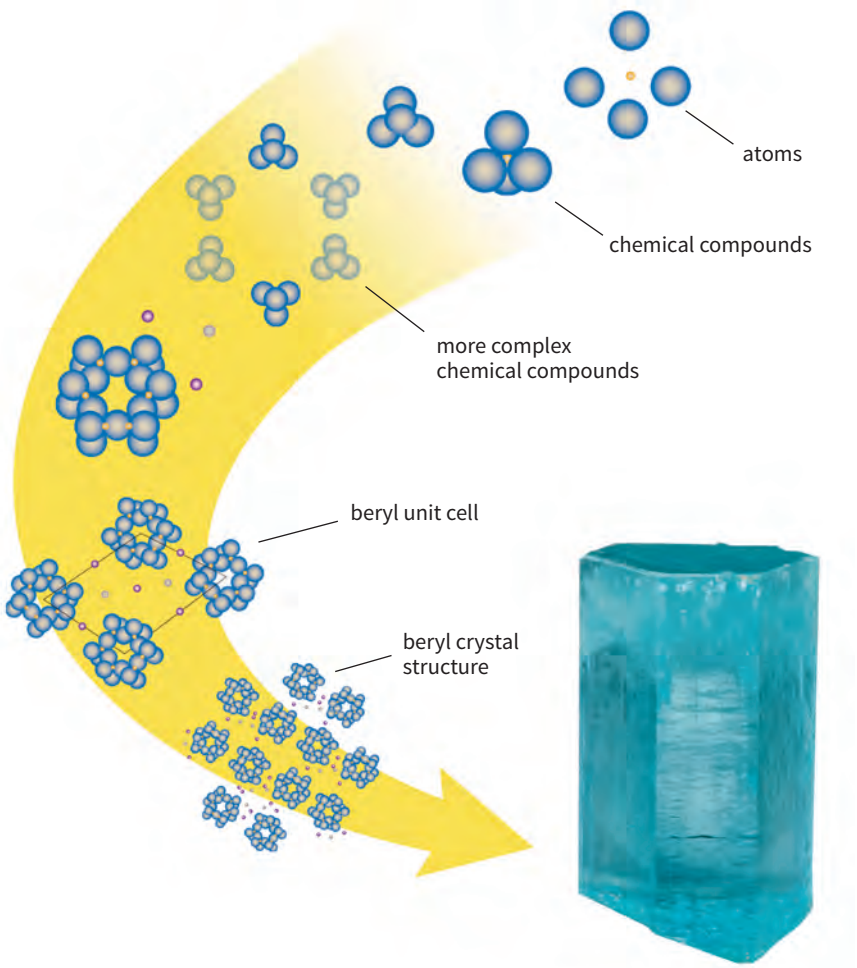
Peter Johnston/GIA

All crystals are built from repetitions of the same basic unit. In this illustration of a beryl crystal, each identical hexagonal component is a unit cell—the smallest part that has beryl's essential structure and chemical composition.

As you learned in Assignment 1, a gem's chemical formula states the kinds and relative quantities of the atoms in its chemical composition. The unit cell, in turn, defines the arrangement of those atoms.

All crystals are composed of unit cells in repeating three-dimensional arrangements. The same factors control the growth of all crystals, from the largest—like the spectacular crystals formed in pegmatite—to the smallest—like the crystals in chalcedony, which can only be seen under the highest magnification.

The way synthetic crystals grow in a lab can shed light on the growth of natural gems. In one synthetic gem growth method, technicians add specific ingredients to a growth medium, called a flux. At the correct temperature and pressure, and as long as conditions remain constant, the chemical ingredients migrate through the hot flux.



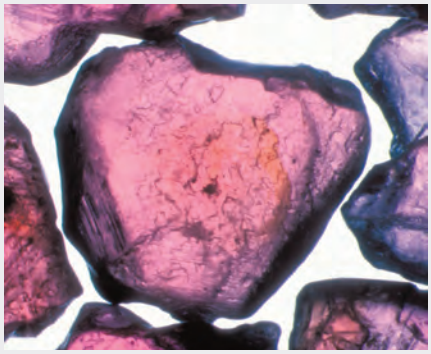
Peter Johnston/GIA

Under the right conditions, and when all the right chemical elements are present in the correct concentrations, atoms come together to form gem crystals. This illustration shows atoms assembling to form beryl unit cells. If there is enough time and space, billions of these unit cells will grow in repeating patterns. The internal symmetry of the beryl unit cell is reflected in the external shape of every well-formed beryl crystal.

Surface Features on Crystals

Robert Weldon/GIA

Corundum crystals commonly display parallel groove-like horizontal growth markings, called striations, on their crystal faces. This sapphire crystal, with a pyramid at each end, is called a tapered bipyramid.

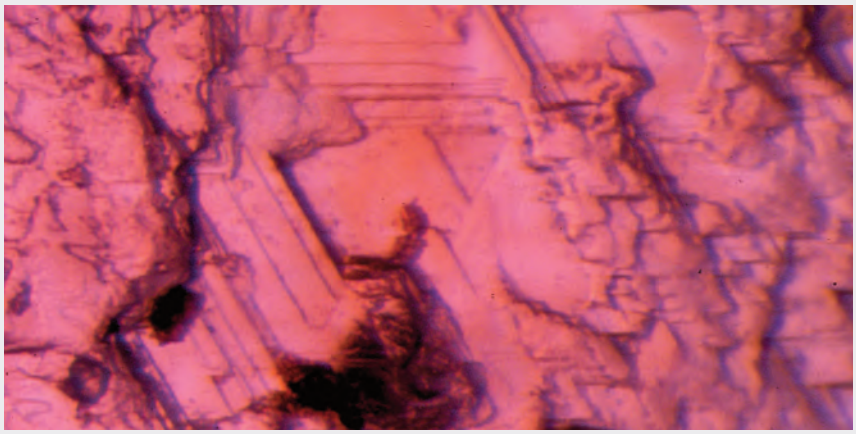


Duncan Pay

These ruby pebbles lack an apparent crystal shape, but they do have triangular growth features that help distinguish them from other gem materials found in alluvial deposits.

Eric Welch/GIA

A spodumene crystal often has triangular etch marks on its surface. Magnification reveals this kunzite spodumene's triangular depressions.

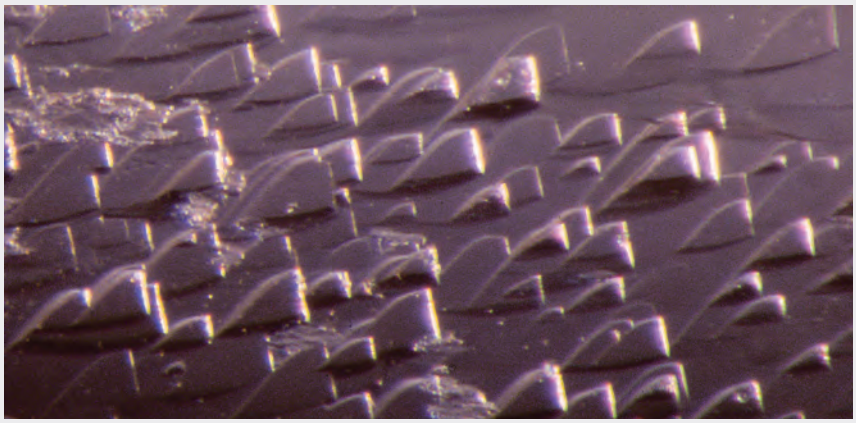


Duncan Pay

A close-up view of this ruby pebble clearly shows its triangular growth markings.

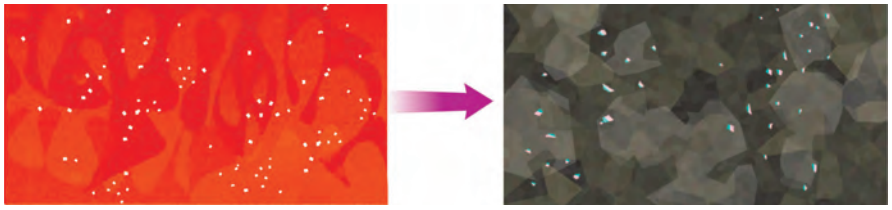
Robert Weldon/GIA

This spessartine garnet crystal has distinctive etched features on its surface.



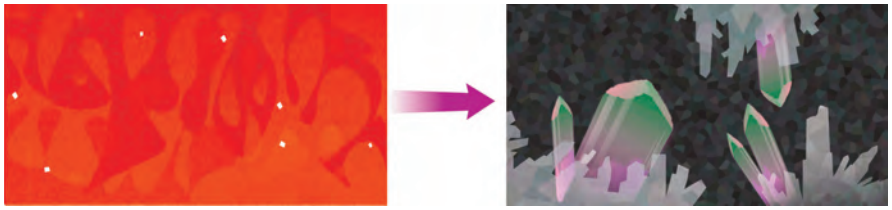
John Koivula/GIA

This spodumene's triangular etch marks all point in the same direction.



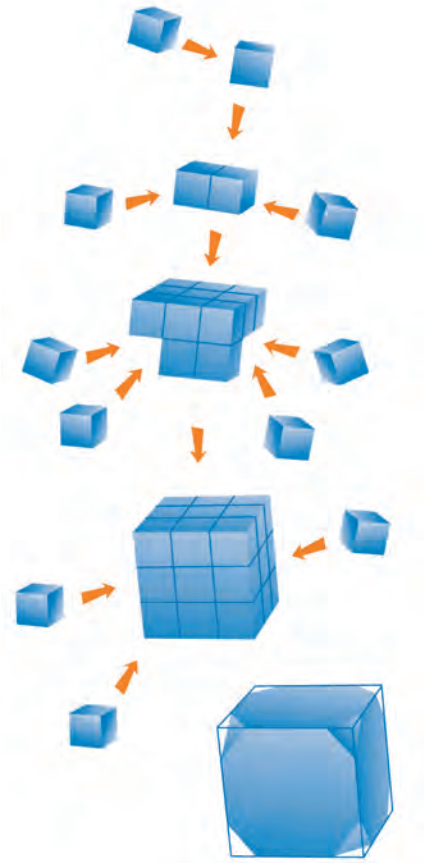
Peter Johnston/GIA

A crystal's size is directly related to its growth conditions. A solution that's highly saturated in nutrients produces many small crystals, resulting in a mass called an aggregate. Rapid cooling produces similar results: A volcanic rock like basalt contains a mass of tiny crystals due to fast cooling.



Peter Johnston/GIA

If cooling is slow, individual crystals have more time to develop. The crystals of granite, which cools more slowly, are much larger than basalt's crystals. In addition, a lower concentration of nutrients leads to fewer crystallization centers, which also results in larger single crystals.



Peter Johnston/GIA

When the necessary chemical ingredients are available, and as the temperature cools, unit cells come together to form clusters. Each cluster is a template for the fully grown crystal.

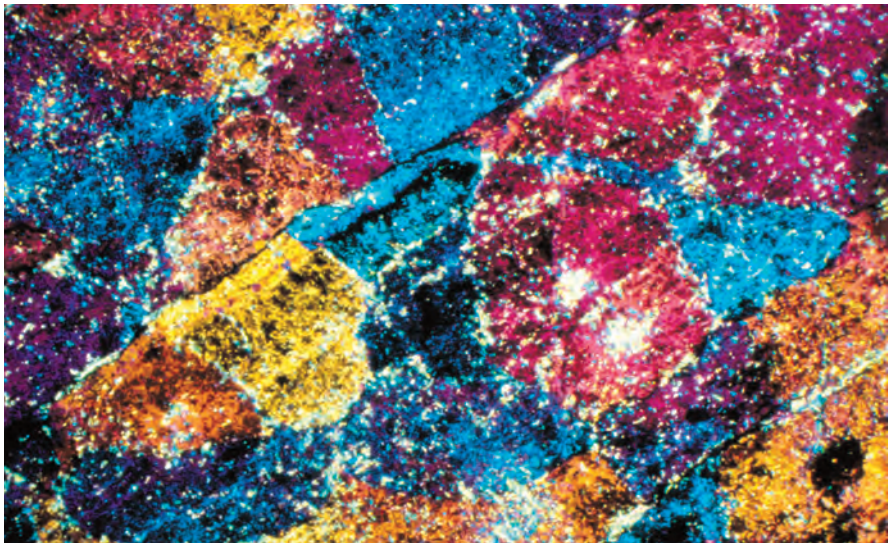
In order for crystals to form, the growth conditions have to change. So they allow the flux to cool, or they add more ingredients until the flux can't hold them in solution any longer.

As the flux cools, the necessary chemical ingredients come together and form a few unit cells. At first, most of the unit cells dissolve back into the flux, but as the temperature drops, more unit cells remain after they form. As they begin to come together—in a stage called nucleation—each little cluster of unit cells acts as a nucleus, or template, for crystal growth.

Cooling time is one factor that controls the growth of developing crystals. When the flux cools quickly, the rate of nucleation is higher than the rate of crystal growth. This results in the formation of many small crystals. If the flux cools slowly, the rate of crystal growth is higher than the rate of nucleation and fewer, larger crystals form.

Concentration of ingredients matters, too. If the flux is very highly saturated with the elements necessary for crystal growth, many small crystals tend to grow. If it's less saturated, fewer crystals will grow, but they'll be larger.

You can demonstrate these processes with a mineral that's soluble in water: common table salt. If you add enough salt to a pan full of water, the water will eventually become so saturated with salt that it can't hold any more dissolved in solution. That's when nucleation starts and crystals begin to form.



John Koivula/GIA

Tino Hammid/GIA

Although it's commonly thought of as a single mineral, sugilite is actually an aggregate composed of sugilite and other minerals, including quartz. Sugilite's interlocking crystals of different minerals are clearly visible in the thin section (above). The fine piece of rough sugilite (right) is from the Wessels mine in South Africa.

Tino Hammid/GIA

Sugilite is widely used for carvings and inlay work. The bracelet inlaid with rich purple sugilite and pavé-set diamonds is a fine example of the gem's potential.

If you turn the heat on under the pan, the heat will eventually cause a large quantity of the water to evaporate. This speeds up the crystallization process. But the crystals that form will be very small. That's because the faster crystallization process "squeezes" more nuclei out of solution and sets up more crystallization centers. The result is a multitude of tiny, randomly oriented crystals, each competing for nutrients.

Gem minerals that are made up of dense, closely packed masses of tiny, randomly oriented crystals are called *aggregates*.

Aggregate—A mass of tiny, randomly oriented crystals.

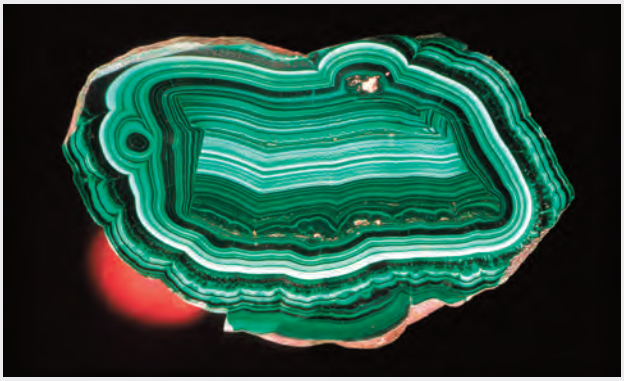
Aggregates

Robert Weldon/GIA

Chalcedony is among the better-known quartz aggregates. It comes in a range of transparencies from opaque to almost transparent and it's used in jewelry and carvings. It's called cryptocrystalline due to the tiny size of its crystals.

Valerie Power/GIA

Aventurine is another aggregate quartz variety. Its crystals are larger than chalcedony's so it's called microcrystalline. The green color and glittery reflections are caused by chrome mica platelet inclusions.



A. Ruppenthal

Malachite is a popular banded green aggregate that's used for beads and cabochons. It's especially useful for carvings because of its relative softness.

Terri Weimer/GIA

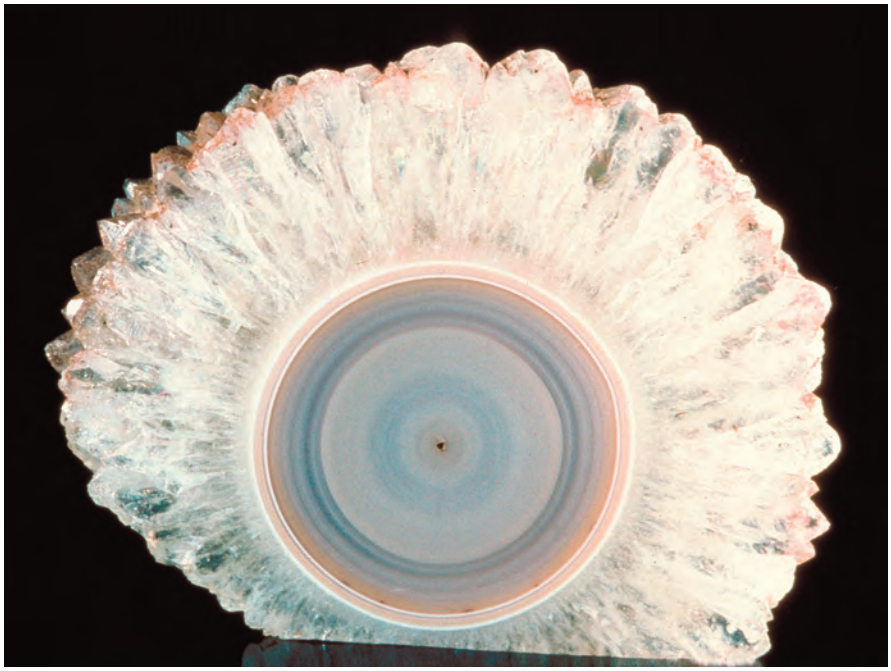
Lapis lazuli is an aggregate that's also a rock because it's composed of more than one mineral. It usually contains lazurite, pyrite, and calcite, but it might also contain other minerals.

Terri Weimer/GIA

Jadeite is an aggregate with an interlocking structure that makes it extremely tough. It's often found in boulder form. Traders polish windows on the boulders to get an idea of the rough's inner quality.

Eric Welch/GIA

Nephrite has an interwoven structure that connects the individual crystals. This makes it slightly tougher than jadeite.



Alan Jobbins

This exceptional radiating aggregate of large colorless quartz crystals is centered on a banded core of chalcedony. The chalcedony is a cryptocrystalline aggregate, made up of tiny quartz crystals too small to be seen without very high magnification.

Robert Weldon/GIA, courtesy Becky Liao

Jadeite is a microcrystalline aggregate. Because of its arrangement of tiny interlocking crystals, articles carved from it are extremely tough and durable.

The individual crystals in aggregates come in a variety of sizes. They might be readily visible, like the radiating crystals that make up rock crystal. They can be *microcrystalline*, like nephrite, jadeite, and quartzite, where the crystals are visible under magnification. They can also be *cryptocrystalline*, like chalcedony and turquoise, where only the highest power magnification (beyond the power of a standard gemological microscope) can detect individual crystals.

No matter what type of crystal is forming, and whether it's synthetic or natural, the crystallization process is basically the same: Atoms come closer and closer together until they finally form connecting bonds. If conditions are right—the right elements and correct temperature and pressure—and there's sufficient space and time, the arrangement of the atoms and their connecting bonds reflects the symmetrical structures that are typical of crystal growth.

Robert Weldon/GIA

Azurmalachite is a rock made up of the aggregate minerals azurite and malachite.

Symmetry, Order, and Shape

Symmetry is everywhere. The buildings that surround us are symmetrical structures, created by skilled architects to provide an eye-pleasing balance of form and proportions. Brick structures, like crystals, are repetitions of tiny, identical units. The way the units—the bricks or unit cells—are stacked gives shape to the structure of the crystal.

Microcrystalline—An aggregate made up of individual crystals visible under magnification.

Cryptocrystalline—An aggregate made up of individual crystals detectable only under very high magnification.

Ricardo Liberato

Human architecture often mimics nature's designs. Like a crystal, this Egyptian pyramid appears seamless from a distance. Up close, its structure of regularly stacked, identical stone blocks—its "unit cells"—becomes apparent.

KEY CONCEPTS

Crystalline minerals are classified into seven crystal systems, depending on the symmetry of their unit cells.

Unit cells stack in three dimensions as a crystal grows. The differences between gems are due to the differences in the proportion and symmetry of their unit cells. Some unit cells are less symmetrical than others because of the types of atoms they're made of and the way those atoms are joined together. All crystalline minerals, including gems, are classified into seven crystal systems, depending on the symmetry of their unit cells.

The Crystal Systems

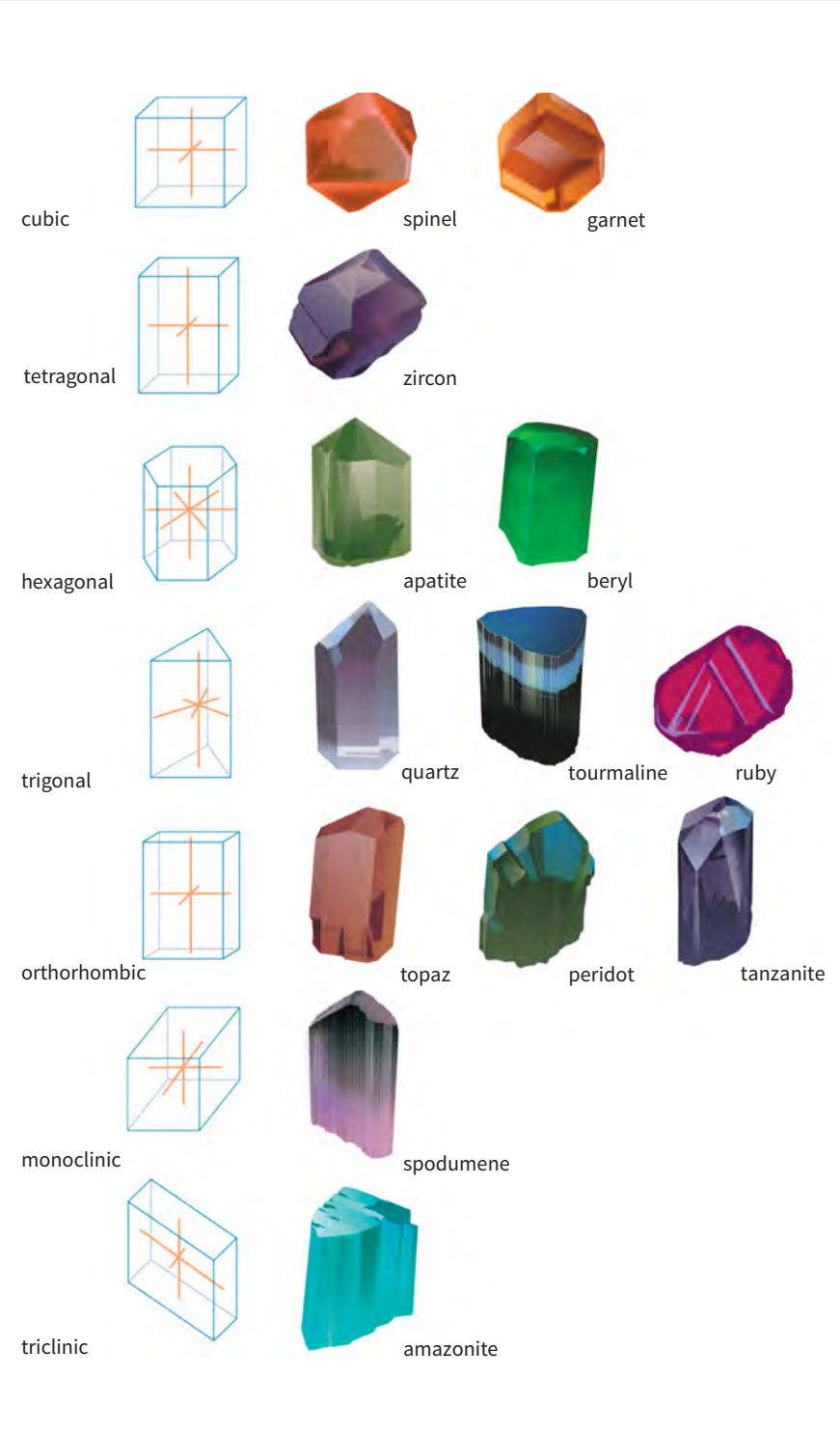
Gems like diamond, spinel, garnet, and fluorite crystallize in the cubic crystal system (sometimes called the isometric system). Cubic minerals have the highest symmetry. A well-formed spinel or diamond crystal has a highly ordered and symmetrical arrangement of crystal faces. This is because their unit cells are also highly symmetrical.

Gems and Their Crystal Systems

Like all other crystalline minerals, gems form in seven different crystal systems. They range from the most symmetrical (cubic) system to the least symmetrical (triclinic) system. Each system has its own characteristic unit cell, and that unit cell helps define the physical properties of the gems in that system.

The illustrations show the differences in symmetry of the unit cells as well as the external results of those differences. For example, if you compare a symmetrical spinel crystal with the chisel-like shape of a topaz crystal or the flattened shape of many ruby crystals, you can see how their shapes are an outer reflection of their different crystal structures.

- Cubic (isometric)—diamond, spinel, garnet, fluorite
- Tetragonal—zircon
- Hexagonal—apatite, beryl
- Trigonal (rhombohedral)—corundum, quartz, tourmaline
- Orthorhombic—topaz, iolite, tanzanite (zoisite), chrysoberyl, peridot
- Monoclinic—kunzite (spodumene), moonstone (orthoclase feldspar)
- Triclinic—amazonite (microcline feldspar), rhodonite



Peter Johnston/GIA

Tino Hammid/GIA

Tino Hammid/GIA, courtesy Colgem Ltd.

Spinel and garnet are both cubic-system crystals. Spinel's (top) typical shape is an eight-sided octahedron. The 1.32-ct. rough spinel and the 0.75-ct. faceted gem are from Myanmar. Garnet's (bottom) typical shape is the rhombic dodecahedron, with 12 equal diamond-shaped faces. These spessartine garnets—a 9.80-ct. rough crystal and an 8.66-ct. faceted gem—are from Namibia.

Jeffrey Scovil, courtesy Larry Conklin

Beryl crystallizes in the hexagonal crystal system. The aquamarine crystal shown here is typical, with its six flat faces and columnar shape. Beryl is elongated in one direction because its crystal structure is less symmetrical than cubic crystals like garnet.

Jeffrey Scovil, courtesy Steve Smale Collection

Crystallizing in the trigonal system, tourmaline crystals are typically long and slender. They have vertical grooves parallel to their length and a rounded triangular cross-section. This tourmaline from Minas Gerais, Brazil, measures 9.2 cm.

Robert Weldon/GIA

Zircon crystallizes in the tetragonal system, producing crystals that are typically square in cross-section. They usually feature four rectangular sides and a pyramid-shaped top with four triangular faces that meet in a point.

The unit cell of a cubic crystal is shaped like a cube. You can stack cubes to build a bigger cube or you can stagger them to build an octahedron, or even a 12-sided figure called a dodecahedron. Rough garnet is typically this shape.

Cubic crystals are more symmetrical than the crystals in other systems. Their external symmetry is made possible by their highly ordered structure at the atomic level. This atomic symmetry gives them fewer directional differences in their physical and optical properties.

Not all crystals have cube-shaped unit cells. Some—like beryl, corundum, and quartz—have six-sided crystals and hexagonal unit cells. Beryl is more symmetrical than the others, so it's classified in the hexagonal crystal system. Corundum, tourmaline, and quartz have less symmetrical unit cells and belong in the trigonal (sometimes called rhombohedral) crystal system.

If you stretch a cube along one dimension, it results in a brick shape, longer in one direction than the others. Crystals with unit cells shaped like this belong to the tetragonal crystal system. This internal structure can affect the physical properties of a gem—such as hardness—or the way a gem interacts with light. The colors of the gem might vary with viewing direction as well. Zircon is an example of a tetragonal gem.

Jeffrey Scovil, courtesy Gene Meieran Collection

Topaz crystallizes in the orthorhombic crystal system. Its crystals are usually elongated with obvious vertical grooves. They feature a diamond-shaped cross section, a flat break at the base due to cleavage, and triangular faces that give the top a chisel shape. This 11-cm example is from Ouro Preto, Brazil.

Jeffrey Scovil, courtesy Gene Meieran Collection

Kunzite spodumene crystallizes in the monoclinic crystal system. This 12-cm kunzite from Afghanistan shows the typical asymmetrical form with vertical grooves. This is often capped by angled flat faces that form an irregular surface.

KEY CONCEPTS

The exterior shape of a crystal often indicates its symmetry at an atomic level.

Now, take the brick and flatten it so that all three directions have different measurements. Crystals built from unit cells shaped like this are even less symmetrical, and they belong to the orthorhombic crystal system. Topaz and peridot both belong to this system.

The angles between the flat faces on the flattened brick are still at 90 degrees. Now, distort the brick so that one set of angles becomes less than 90 degrees. You've made a much less symmetrical unit cell. Crystals shaped like this belong to the monoclinic crystal system. Kunzite is a gem in the monoclinic system.

If you distort the brick so no angle is 90 degrees, you've arrived at the least symmetrical crystal unit cell. Rhodonite and labradorite feldspar have unit cells of this type, and belong to the triclinic crystal system.

Because of differences in crystal structure in triclinic gems, some of them—including the gem kyanite—vary in hardness across different directions. Kyanite's Mohs hardness is 4.5 to 5 along the length of its crystal and 6.5 to 7 across its width. This directional difference in hardness is reflected in an older name for kyanite—disthene—which means "two strengths." Kyanite's directional differences are so extreme that transparent kyanite shows different colors at different viewing angles. Once rare, kyanite is now a fairly common sight at gem trade shows.

Alan Jobbins

Microcline feldspar (amazonite) crystallizes in the triclinic crystal system, the least symmetrical of the seven crystal systems. This crystal shows the usual "blocky" shape and angled faces.

Jeffrey Scovil, courtesy Mel Gortatowski Collection

Quartz, represented by these amethyst crystals (top), is relatively plentiful because it's made of the two most abundant elements in the earth's crust—silicon and oxygen. Formation of the emerald crystal (bottom) also required the presence of the less-plentiful elements beryllium and chromium, so it's much rarer.

The Rarer the Ingredients, the Rarer the Gem

Look in the display cases of almost any jewelry store. Which colored stones are the most abundant? Red garnets, amethysts, and treated blue topaz outnumber more costly emeralds and rubies many times over. Some—like treated blue topaz—are available in impressively large sizes at relatively low cost.

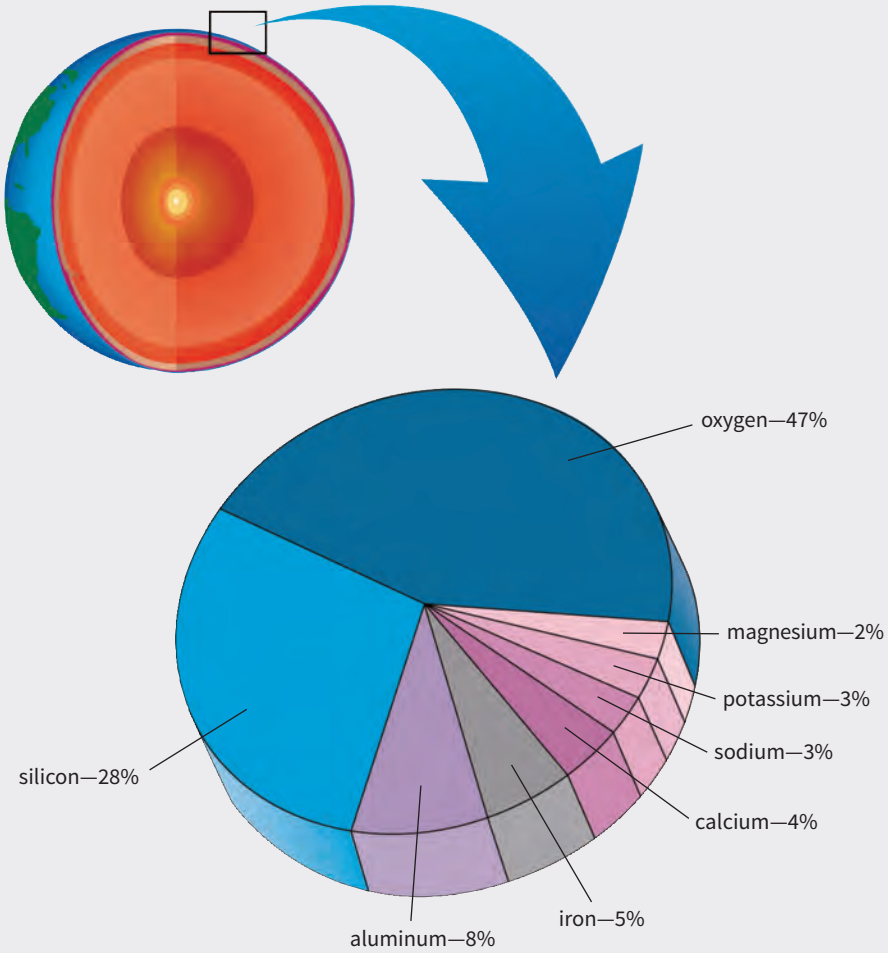
Crystals are the raw material for all these gems. Most rock and mineral crystals are formed from the eight most abundant chemical elements in the earth's crust: oxygen, silicon, aluminum, iron, calcium, sodium, potassium, and magnesium.

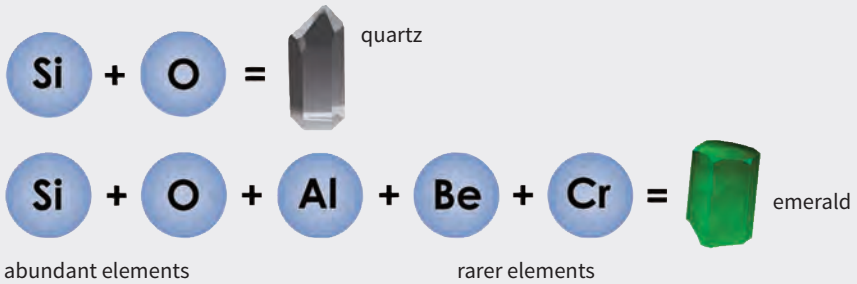
To grow at all, gems like beryl, tourmaline, and kunzite need tiny amounts of elements that are so scarce that it's difficult to express their concentration as a percentage (parts per hundred). Instead they're described in terms of parts per million. Chromium, the element that makes emerald green and ruby red, is only present in 100 parts per million in the earth's crust.

Beryl needs oxygen (its chemical symbol is O), silicon (Si), and aluminum (Al), plus the element beryllium (Be), to form. While oxygen, silicon, and aluminum are relatively abundant, beryllium is rare. The rich green hue of emerald, the most valuable variety of beryl, requires the addition of chromium (Cr). To bring all the necessary components of emerald together at the same time, beryllium-bearing rocks like granite or pegmatite must come into contact with rocks that contain chromium.

These special geological requirements are what make emeralds so rare. By contrast, quartz—which requires only oxygen and silicon to form—forms readily in a variety of different geological environments. As a result, quartz is one of the most common gem materials.

If an element that's necessary for building or coloring a gem is rare, that gem will be rare too. It will also be more expensive than one where all the necessary elements are common. These factors influence the relative abundance—and the cost—of the stones you see in jewelry.





Si = silicon
O = oxygen
Al = aluminum
Be = beryllium
Cr = chromium

Peter Johnston/GIA

KEY CONCEPTS

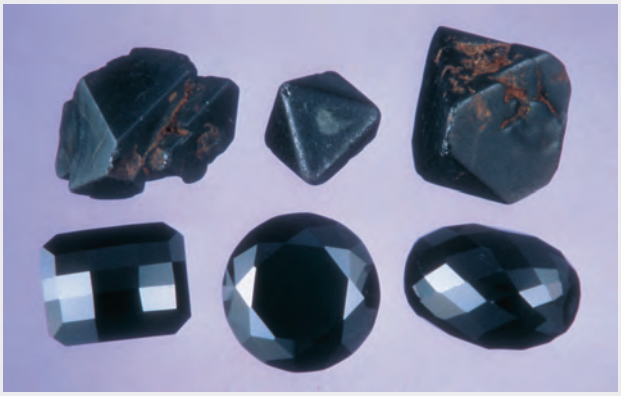
Some gems are rare because they require rare chemical elements or unique geological conditions, or both, to form.

Crystal Systems

Cubic Crystals

Wendell Wilson

These hessonite garnet crystals have crisp crystal faces with high luster. Dodecahedral faces are clearly visible in the crystal on the right.



Maha Tannous/GIA

Black spinel looks very different from the transparent red, pink, violet, and blue varieties, but you can still find octahedral and twinned crystals.

Robert Weldon/GIA

Garnet is a well-known colored gemstone that belongs to the cubic or isometric crystal system. These three crystals display garnet's most common crystal form: the dodecahedron.

Joel Beeson/GIA

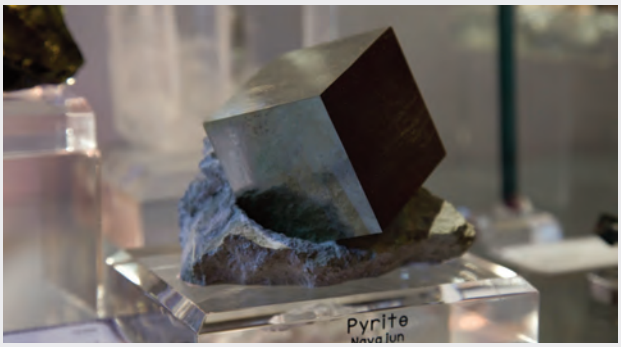
You can easily see where the triangular faces rotated and are pointing away from each other in this twinned spinel crystal.

Robert Weldon/GIA

Fluorite's common habit is a cube.

Robert Weldon/GIA

The twinning plane is visible at the right front corner of this flattened spinel crystal.



Valerie Power/GIA

Pyrite is a gem material that's commonly cube-shaped.

Tetragonal Crystals

Wendell Wilson

Within this cluster of crystals, you can recognize the zircons by their distinctive four-sided—tetragonal—shapes and pyramid terminations.

Jeffrey Scovil

Scapolite is a tetragonal gem that usually crystallizes as a four-sided columnar crystal with a pyramid termination.

Hexagonal Crystals

Robert Weldon/GIA

This hexagonal emerald crystal features an elongated columnar, or prismatic, crystal form, along with six symmetrical faces and incredible color.

Eric Welch/GIA

This large aquamarine crystal has extremely sharp crystal faces, making its six-sided form and flat-faced termination readily apparent.

Wendell Wilson

While it has the same six-sided form as other beryls, morganite is usually flatter than the aquamarine variety.

Mike Havstad/GIA

Apatite forms in the hexagonal crystal system. Its crystals are commonly six-sided, but they terminate in a pyramid.

Trigonal Crystals

Terri Weimer/GIA

Corundum forms in the trigonal crystal system, which is similar to the hexagonal system but with more triangular symmetry. These are typical ruby crystals: six-sided, with a flat, tabular shape.

Robert Weldon/GIA

This quartz crystal has pyramids at both ends. This unusual arrangement is called a Herkimer diamond because it was found in a location known for producing this shape and because it roughly resembles an octahedral diamond crystal.

© Richard W. Hughes/www.ruby-sapphire.com

This incredible 10,100-ct. ruby crystal from Mogok, Myanmar, is still in its marble host rock. The exposed portion shows three of its six sides, along with several shorter tabular crystals.

Robert Weldon/GIA, courtesy Bill Larson, Palagems.com

This bipyramid sapphire crystal has horizontal parallel groves called striations across all six of its crystal faces.

Robert Weldon/GIA

These intergrown quartz crystals are surrounded by orange garnet crystals. The quartz crystals show characteristic horizontal striations on their crystal faces. The larger crystal terminates in an almost perfect six-sided pyramid.

Brendan Laurs/GIA

These tourmaline crystals have prominent vertical striations and distinctive trigonal symmetry that terminates in a pyramid shape. Tourmaline crystals are usually three- or six-sided prisms with rounded triangular cross-sections.

Orthorhombic Crystals

Robert Weldon/GIA

This pale pink topaz crystal features a chisel-shaped pyramid termination.

Robert Weldon/GIA

Topaz forms in the orthorhombic crystal system. Its crystals are often four-sided elongated prisms with vertical striations and a chisel-shaped termination. The bottom is usually flat due to cleavage.

Robert Weldon/GIA

Chrysoberyl forms in the orthorhombic system. It can form as prismatic crystals but is often found as cyclic twins with non-parallel twinning planes, like the crystals at left and center.

Eric Welch/GIA

Orthorhombic peridot can form as a short crystal with vertical striations and a dome or pyramid termination.

Monoclinic Crystals

Robert Weldon/GIA

Spodumene is a monoclinic gem mineral. Its shape is often an elongated prism with vertical striations. This crystal has a pyramid-shaped termination.

Robert Weldon/GIA

Diopside, another monoclinic gemstone, usually forms as a columnar prism with a pyramid or dome termination.

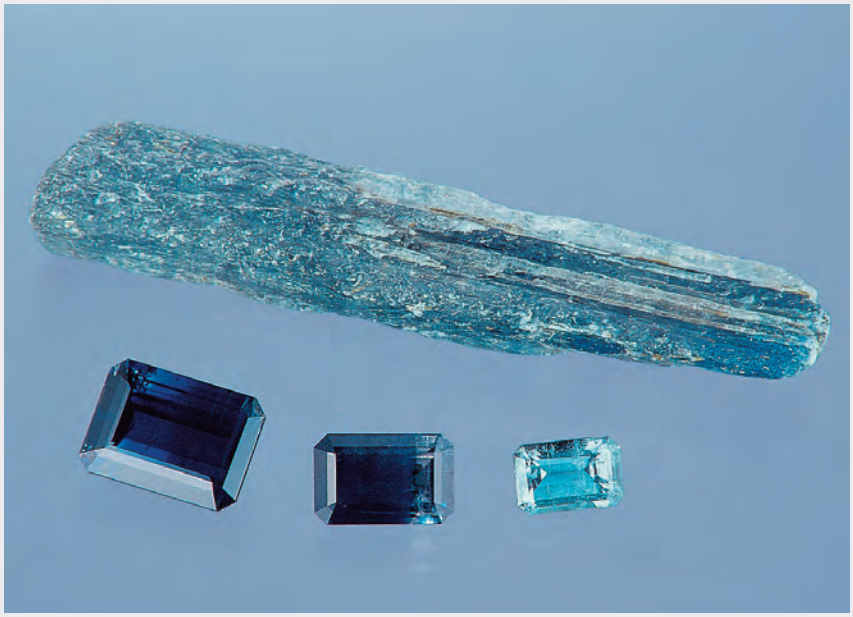
Robert Weldon/GIA

Orthoclase is a species in the feldspar group. It forms in the monoclinic crystal system, and its crystals are often blocky and wedge-shaped.

Triclinic Crystals

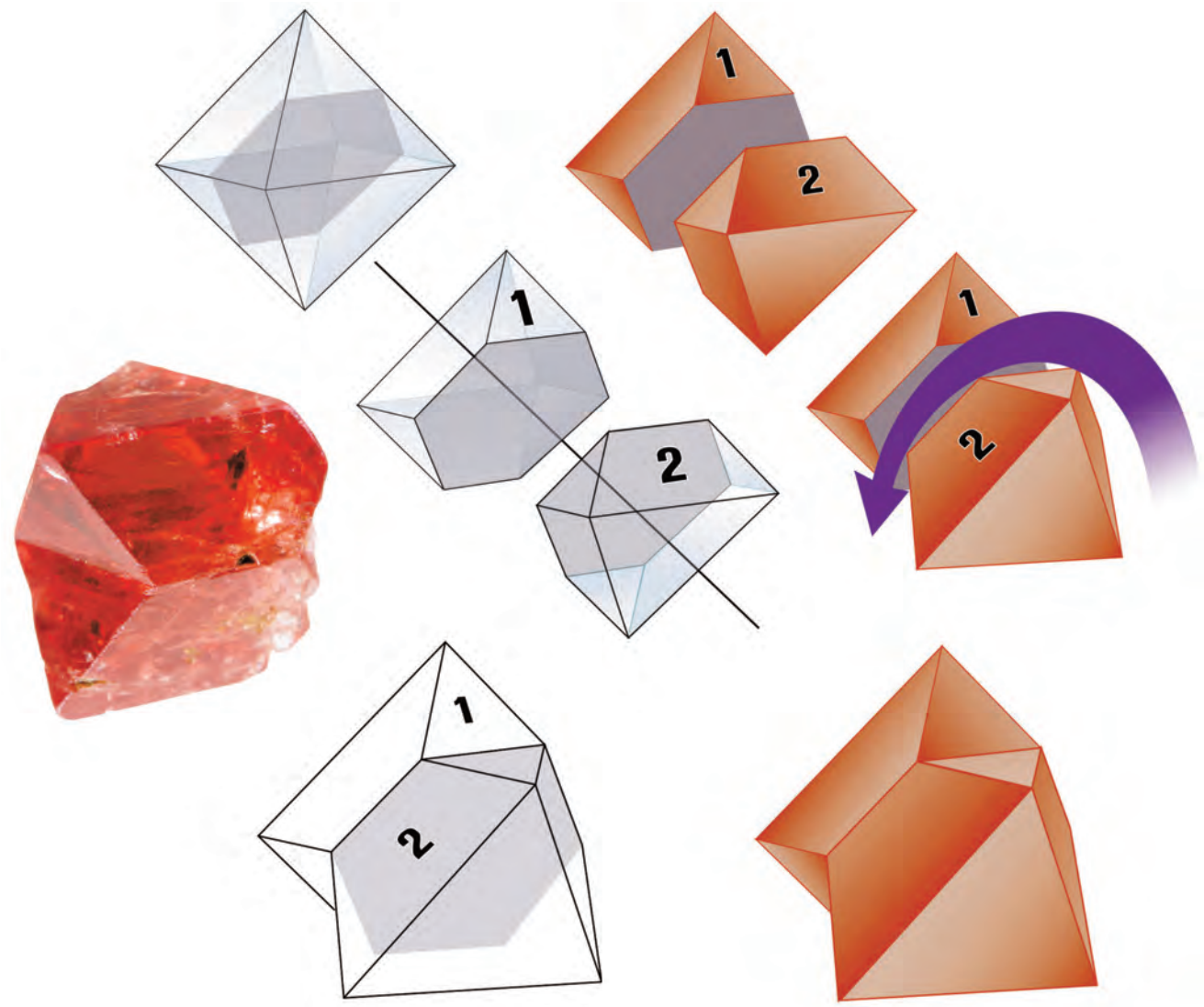
Robert Weldon/GIA, courtesy William F. Larson

The blocky structure is apparent on this amazonite crystal.



Maha Tannous/GIA

Kyanite is a triclinic mineral that forms long, flat, often blade-like prisms. It is commonly color-zoned, with a fibrous appearance.



Peter Johnston/GIA

A spinel twin looks as if the whole crystal was twisted around a plane at its center. This plane is called a twinning plane. In the photo, the twinning plane runs horizontally into the crystal, starting between the two identical triangular faces. In the diagrams, the plane is shaded in darker gray.

Twinning

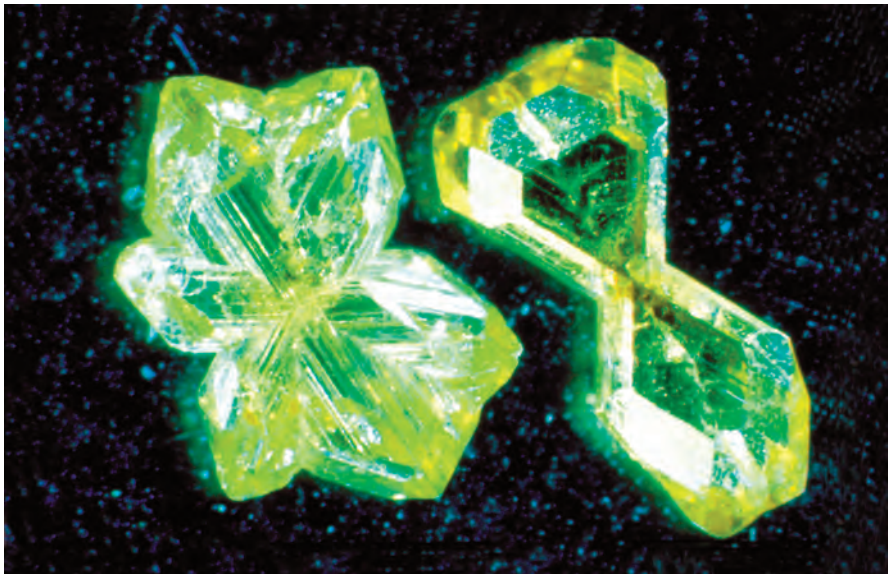
Sometimes a crystal's growth is interrupted early in its formation by a change in its growing environment. Then, when growth begins again, it might not follow the same direction as before, even though it still has the same form as the existing crystal. This change in a gem's crystal direction is known as *twinning*.

If twinning happens during a crystal's original growth period, it's known as primary twinning. In one type of primary twinning, the twinned crystals look like one half is a mirror image of the other. These are known as contact twins, and are seen so often in spinel that they are sometimes also called spinel twins.

Twinning—Change in a gem's crystal direction during or after growth.

KEY CONCEPTS

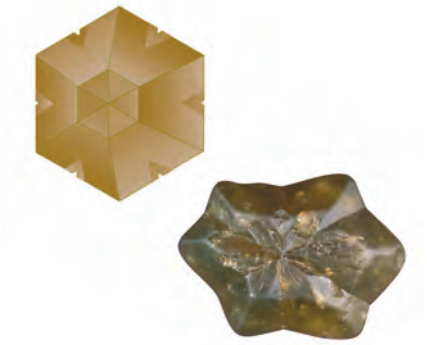
Twinning can result from a change during crystal growth, or from cooling or pressure after the crystal has grown.



Alan Jobbins

These very different-looking twinned crystals are both chrysoberyl. The crystal on the right is a contact twin, with one side a mirror image of the other. The example on the left is a cyclic twin. In cyclic twins, the twin planes are not parallel. They consist essentially of three crystals that appear to have grown through each other.

Twinning plane—Location of a change in crystal growth direction.



Peter Johnston/GIA

Chrysoberyl crystals are frequently twinned. This type of twin, called a cyclic twin, results when twinning planes aren't parallel.

Peter Johnston/GIA

Fluorite is a good example of penetration twinning. It has the appearance of two cubes growing through each other.

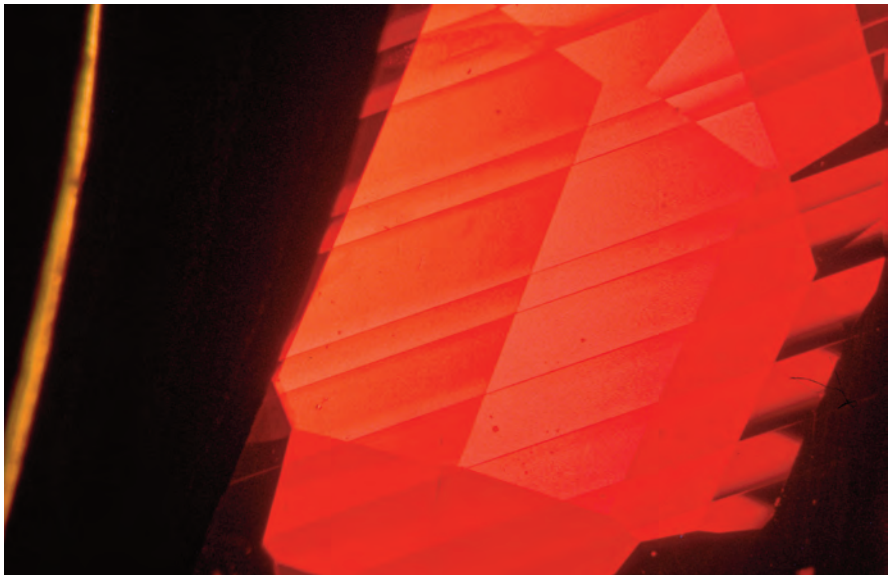
It's easiest to visualize a contact twin as a single crystal that's been cut in half, with one half rotated 180°. Each half is identical, but the crystal's structure appears to be reflected in the plane where the two halves come together. This *twinning plane* marks the location where the direction of the gemstone's crystal structure changed during growth.

Some twinned crystals look as though two crystals have grown through one another. Fluorite and quartz show this type of twinning, which is known as penetration twinning. Cyclic twinning occurs when the twinning planes aren't parallel, and it results in a wheel-shaped crystal. Like contact twins, penetration and cyclic twins occur during crystal growth, so they're also examples of primary twinning.

Twinning doesn't happen only while crystals are growing. Changes in environment after a crystal has formed might also cause twinning. In this case, it's called secondary twinning, and it can be caused by cooling temperatures or the pressure of metamorphism.

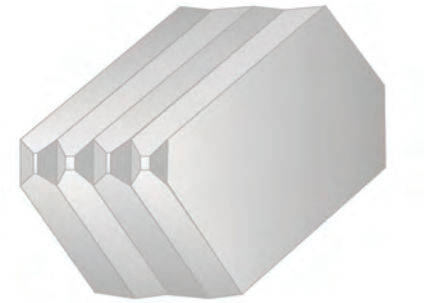
If a crystal forms at high temperatures, its structure might change as it cools. Twinning can occur as the mineral rearranges its structure to conform to the lower temperature conditions. This often happens in feldspars.

Some crystals might start out untwinned, but become twinned when the rocks they formed in are altered by pressure during metamorphism. This type of mechanical stress causes the closely spaced parallel twin planes often seen in corundum and feldspar crystals. This repeated twinning is known as polysynthetic or lamellar twinning.



R. W. Hughes

Polysynthetic twinning in this faceted Thai ruby can be seen readily with the correct illumination under low-power magnification, or even with the unaided eye.



Peter Johnston/GIA

In polysynthetic—sometimes called lamellar—twins, the boundaries between the twinned crystals are parallel. This diagram of a twinned feldspar crystal shows each individual twin crystal in a different shade. Polysynthetic twins result from metamorphic pressure after the gem has formed.

Gem materials that are commonly twinned include quartz, spinel, corundum, feldspar, and chrysoberyl. Twinned crystals often look entirely different from untwinned gems of the same species.

Twinned diamond crystals present a problem to the cutter. Traditional diamond cutting methods make use of a cutting blade coated with diamond crystals. A cutter can saw all the way through an untwinned rough diamond by following the diamond's best sawing direction. If the direction of the diamond's crystal structure changes, as it does in a twinned diamond, the best sawing direction isn't continuous through the stone. Colored stones are softer than diamond, so twinned colored stones don't present the same cutting difficulties as twinned diamond crystals.

Joel Beeson/GIA

Twinned crystals can look very different from untwinned examples of the same species. If you compare the spinel twin and the untwinned crystal, you can see how the corresponding crystal faces relate to one another.

Inclusions

Like twinning, *inclusions* are a natural consequence of crystal growth. An inclusion is a characteristic contained within a gemstone, or one that reaches its surface from the interior. But inclusions are more than just interruptions in a crystal's structure. They can help identify a gem, give clues to its natural or synthetic origin, tell whether or not it's been treated, and also affect its beauty and durability. As a result, inclusions can influence a gemstone's value.

Inclusion—A characteristic enclosed within a gemstone or reaching its surface from the interior.

Inclusions are a byproduct of natural crystal growth. No gem grows in isolation, and almost every cut gem carries some trace of the different minerals it grew with. A calcite inclusion in a faceted ruby is a reminder of the marble that the gem formed in. The tiny black chromite crystals in peridot are souvenirs from the earth's mantle. Emeralds that grow in metamorphic rocks might inherit flat plates of biotite mica and needles of actinolite from the rock around them.

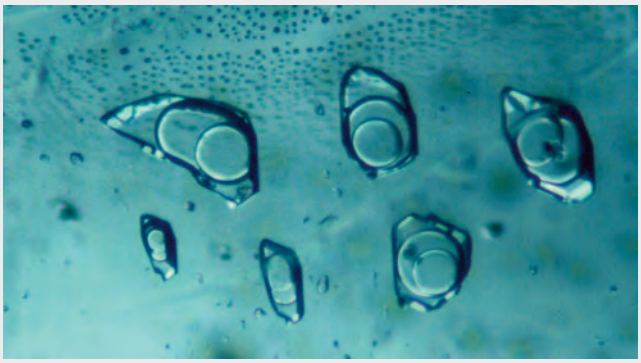
Inclusions

Nathan Renfro/GIA

The three-phase inclusions in this emerald contain a liquid, a solid, and a gas. The liquids have geometric outlines, while the gas bubbles are round and the solid crystals are cubic or elongated and transparent.

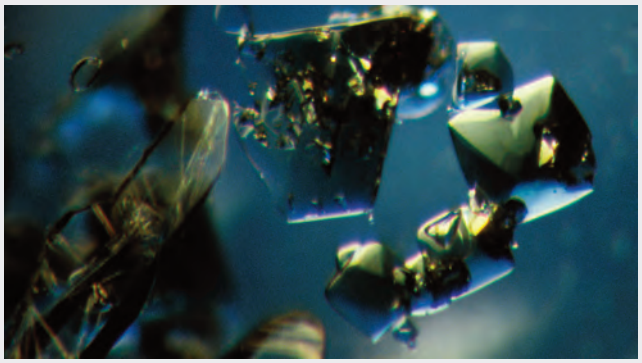
Maha Tannous/GIA

Inclusions in the quartz rough and finished gem contain a mixture of water and petroleum. The crystal has terminations at both ends.



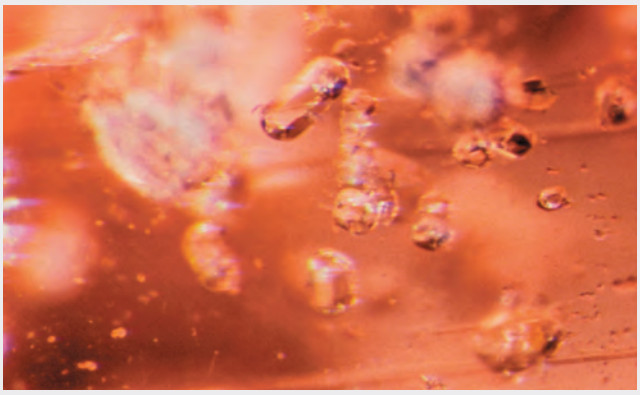
Anthony de Goutière

It is common for multi-phase inclusions in topaz to contain two liquids that do not mix, with a gas bubble trapped inside one of the liquids.



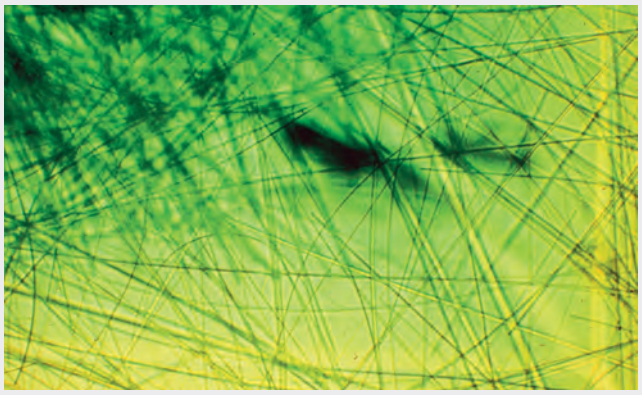
John Koivula/GIA

Mineral inclusions can tell us a great deal about the stones that contain them. This spinel crystal in a Sri Lankan sapphire identifies the stone as natural and helps determine how and where it formed.

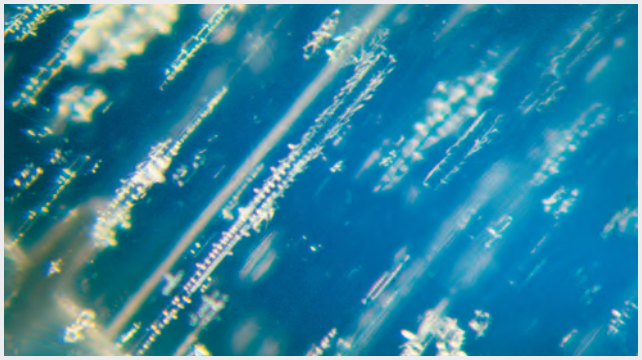


Duncan Pay

These apatite crystals in corundum lack well-defined outlines, but enough of their form can be detected to help with identification.

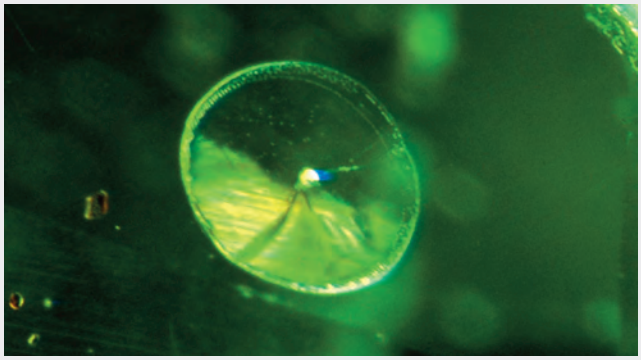


These long, thin, curving needle inclusions are composed of the mineral tremolite. They are distinctive features of emeralds from the Sandawana Valley of Zimbabwe.



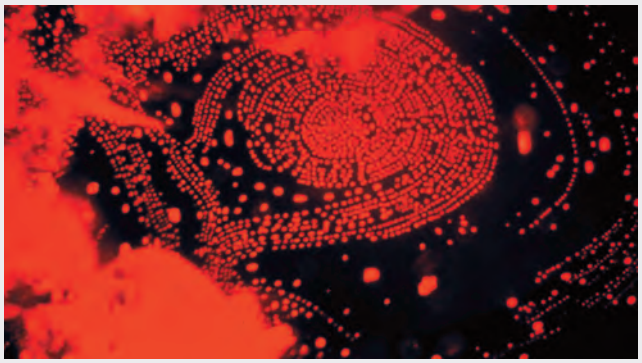
Edward Gübelin/GIA

Descriptive inclusion names can reflect their appearance rather than their actual composition. These inclusions in an orthoclase moonstone are called centipedes. They're caused by fine stress cracks parallel to cleavage directions.



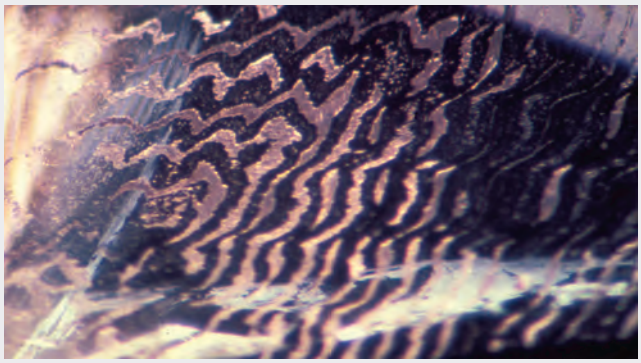
Alan Jobbins & Duncan Pay

"Lilypad" is a descriptive term for an inclusion found in some peridot. It has a hollow space, called a negative crystal, in the center and a disk-like stress crack around it.

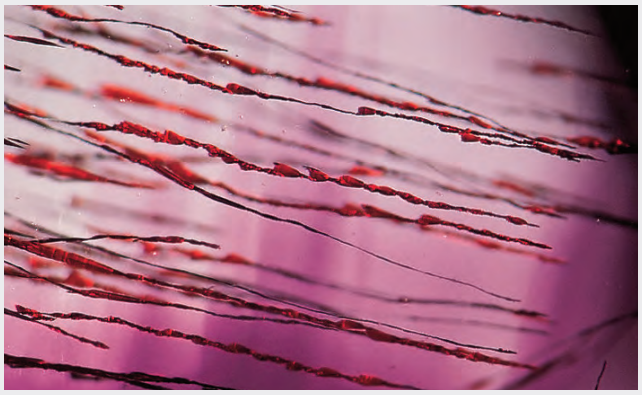


Michael Waitzman/GIA

This inclusion strongly resembles the pattern of a human fingerprint. Fingerprint inclusions can be made up of individual crystals, negative crystals, multi-phase inclusions, or interconnecting liquid inclusions.

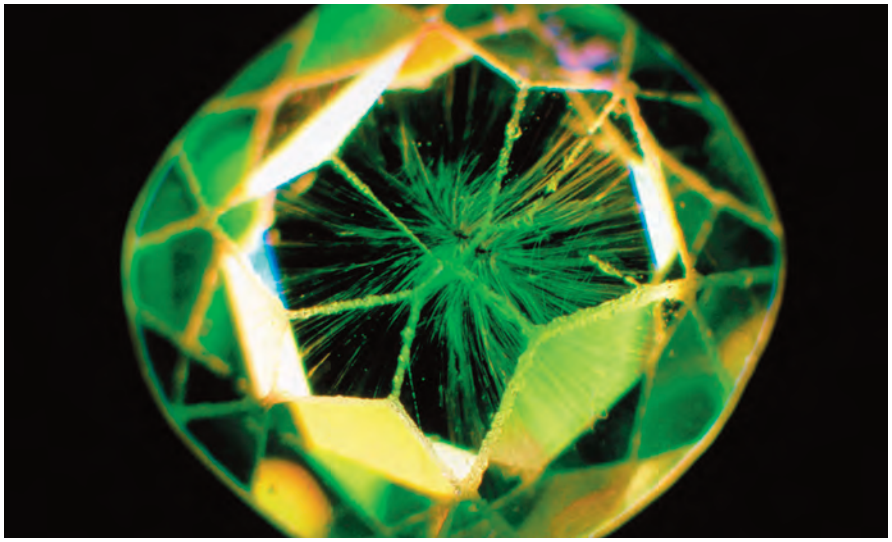


Amethyst can contain so-called "zebra stripe" inclusions. They consist of liquid-filled channels that form this pattern due to growth disturbances and twinning.



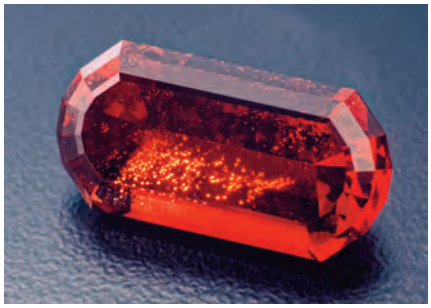
John Koivula/GIA

Deep red hematite needles complement the reddish purple color of this amethyst from Nigeria.

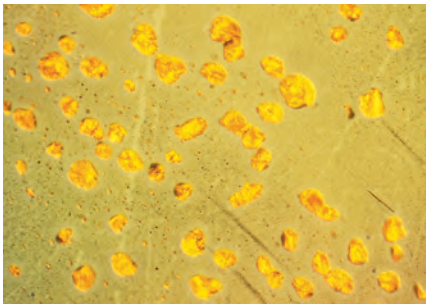


Alan Jobbins

A tiny chromite inclusion under the table facet of a fashioned demantoid garnet radiates golden mineral fibers. This "horsetail" inclusion is unique to demantoid, so it allows positive identification of the gem and adds to its value. For this reason, the cutter oriented the stone so the inclusion appears under the table.



Robert Weldon/GIA, courtesy Larry Gray



C. Johnston/GIA

The sparkling copper crystals in this 10.76-ct. sunstone feldspar from Oregon (left) are the cause of its aventurescence. The photomicrograph (right) shows the individual copper platelets, randomly oriented within specific planes.

KEY CONCEPTS

Inclusions in a colored stone can help identify it as natural or manmade, untreated or treated.

Large inclusions can dramatically affect beauty, value, and durability.

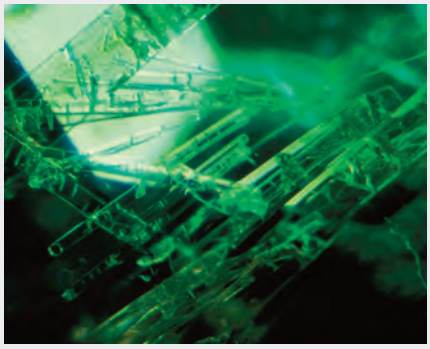
An inclusion can be a distinct mineral crystal of any size, shape, or color. It can be a cloud of minute particles or a hollow cavity filled with a combination of a liquid, a gas, and sometimes also a solid crystal. Color zoning (caused by variations in coloring impurities) and fractures (caused by stress to the crystal) are also classified as inclusions.

Inclusions are often the key to a colored gem's identity. They can help separate a gem that grew in the earth from one that grew in a laboratory. For example, a tiny cluster of rutile needles in a fine ruby is nature's signature, and assurance of that stone's rarity and value. In rare cases, inclusions can even help establish the geographic origin of an important ruby, sapphire, or emerald.

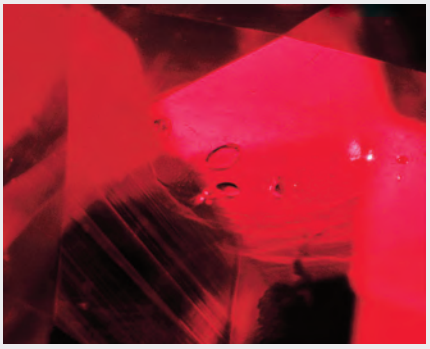
Inclusions can cause phenomenal effects. Without inclusions, there would be no cat's-eye chrysoberyl, no star sapphire, and no aventurescent "sunstone" feldspar.

Inclusions and Crystal Growth

Before



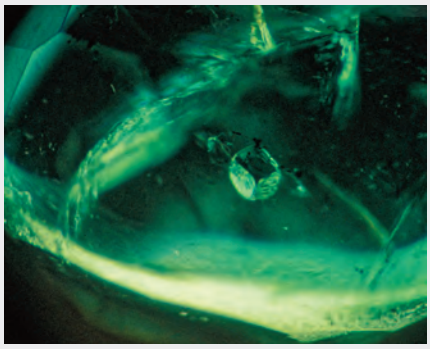
John Koivula/GIA



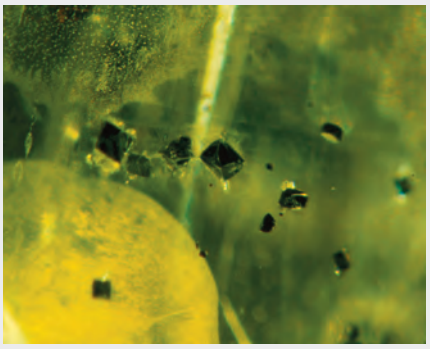
Robert Kane/GIA

These inclusions (actinolite rods in emerald and calcite in ruby) formed from minerals already present in the rocks as the gems grew. Inclusions like these are generally rounded without sharp faces.

During



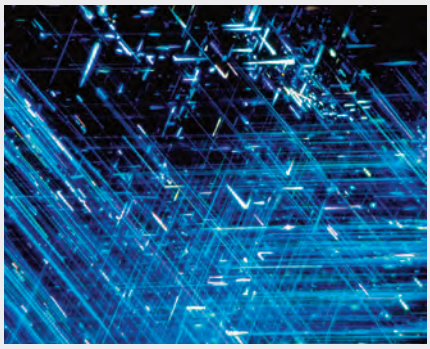
John Koivula/GIA



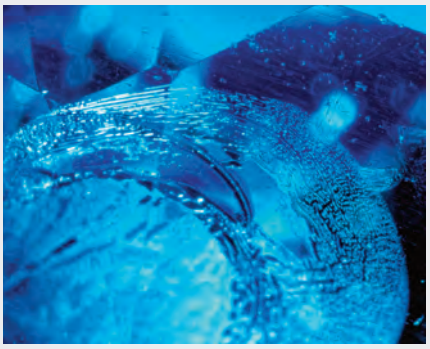
John Koivula/GIA

Pyrite crystals in quartz or emerald, or chromite inclusions in peridot, are minerals that grew at the same time as the gem. Their crystal faces tend to be sharp and well formed.

After

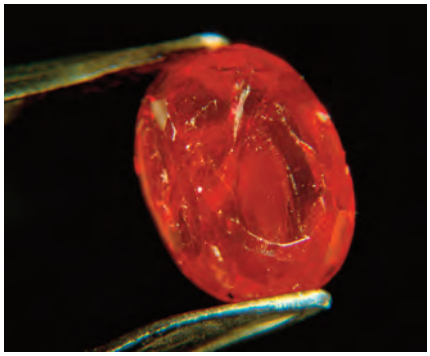


Clayton Welch/GIA



Clayton Welch/GIA

Rutile needles in sapphire, and fingerprints in rubies, sapphires, and other gems, result from events that occur after the gem crystallizes. Rutile forms from trace elements forced out of the gem's structure as it cooled. Fingerprints result from the healing of fracture surfaces by growth fluids, sometimes long after a gem has formed.



Andrew Quinlan/GIA

The prominent surface-reaching fractures in this 2.55-ct. ruby were probably caused by heat treatment. Extensive inclusions like this raise questions about a stone's durability, reducing its value and making it more difficult to sell.

Liquid inclusion—Small pocket in a gem that's filled with fluids and, sometimes, gas bubbles and tiny crystals.

Two-phase inclusion—A hollow cavity in a gem, usually filled with a liquid and a gas.

Three-phase inclusion—A hollow cavity in a gem filled with a liquid, a gas, and one or more crystals.

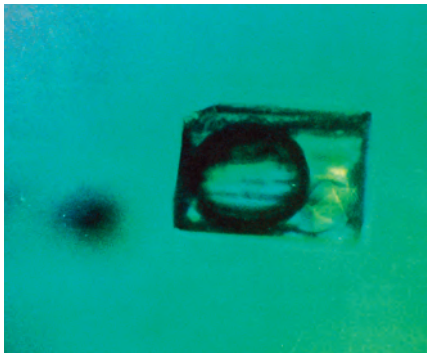
Inclusions can have their negative effects, too. A large, prominent mineral inclusion can disfigure a gem, and clouds of smaller crystals can reduce transparency and value. Fractures in stones compromise durability, which can make them more difficult to sell.

One way to understand inclusions is to consider when they formed in relation to the gem itself. Some inclusions are already formed when they become part of the gem they're enclosed in. As gem crystals grow, they might enclose existing minerals from the surrounding rock. These minerals then become inclusions within the gem. Sometimes, mineral inclusions have sharp, well-formed crystal faces. Usually, however, the inclusions are partially dissolved by the surrounding gem, so their edges are rounded. You'll see this effect in the calcite or spinel crystals within the rubies that form in marble deposits.

Some inclusions form at the same time as the gem. The conditions that a crystal grows in might allow the growth of many other mineral species at the same time. If the gem crystal develops faster than the minerals around it, it might enclose them completely, preserving them as inclusions. The "brassy" metallic pyrite crystals in some emeralds are good examples. The crystals grew along with the gem, so their crystal faces are sharp and angular.

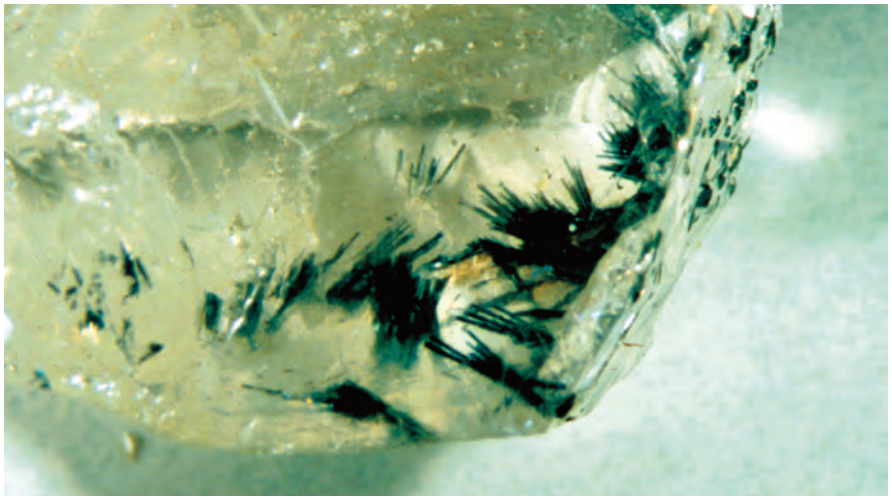
Gems that grow in mineral-rich watery solutions often enclose liquids. Topaz, emerald, and amethyst can have abundant *liquid inclusions*—hollow, fluid-filled cavities. Sometimes they also contain a gas or a solid, or both. When only two of those things are present—typically liquid and gas—they're described as *two-phase*. If all three are present, it's described as *three-phase*.

The characteristic three-phase inclusions in emeralds from Colombia, Afghanistan, Zambia, and China are important keys to their identification. Scientists have also used them to get more information about emerald formation in these deposits. You'll learn more about these emerald sources in Assignment 15.



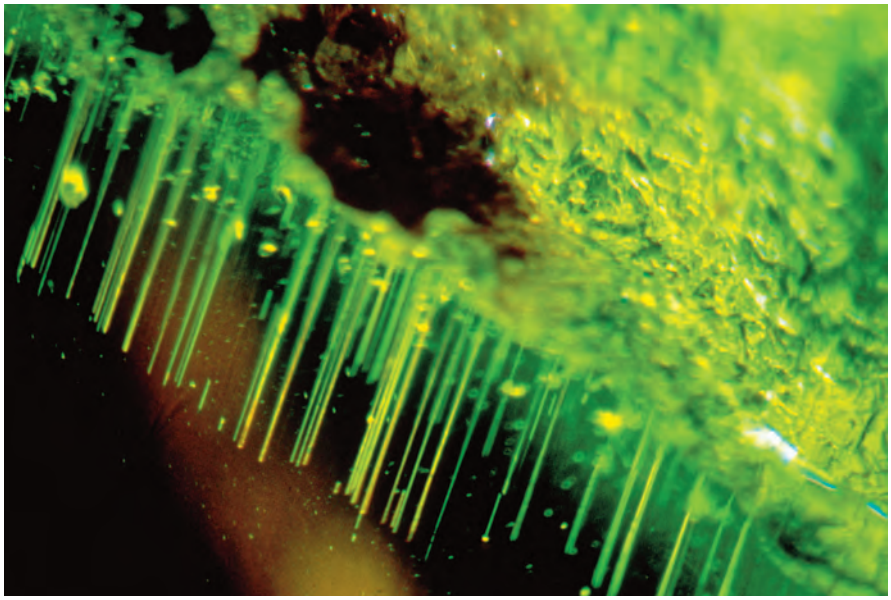
Julio Cesar Mendes and Juarez Leal de Souza

Trapped within a tiny cavity in this Brazilian emerald is a three-phase inclusion that consists of a liquid, a bubble of gas (probably carbon dioxide), and a tiny crystal. These minute features offer gemologists valuable clues to the emerald's formation.



Bruce Cairncross

When different gems form under the same conditions, they often trap and preserve one another's features within their crystals. This topaz from Klein Spitzkoppe *(Kline Spits-copy)*, Namibia, contains dark greenish blue tourmaline crystals that were engulfed as both gems grew in a pegmatite.



John Koivula/GIA

Growth tubes are common features in tourmalines of all colors. They result when tiny inclusions block growth and the tourmaline crystal grows around them. This produces hollow tubes that trail out behind each inclusion. (20X)

If a tiny inclusion blocks crystal growth, the crystal will sometimes grow around and past it. As this happens, a long hollow tube trails out behind the inclusion in the growing crystal. When many inclusions are involved, a series of parallel hollow lines might result. These are called growth tubes. They're often seen in tourmaline, where they can produce a cat's-eye effect if the stone is cut correctly.

Some fluid inclusions can form after the gem that contains them—even millions of years later. If there is sufficient crystal growth fluid present around an already-formed gem, it can get into an existing surface-reaching crack and "heal" it. When the liquid "leaks" along the plane of the crack, some of it is trapped. This forms a pattern that looks like a fingerprint.

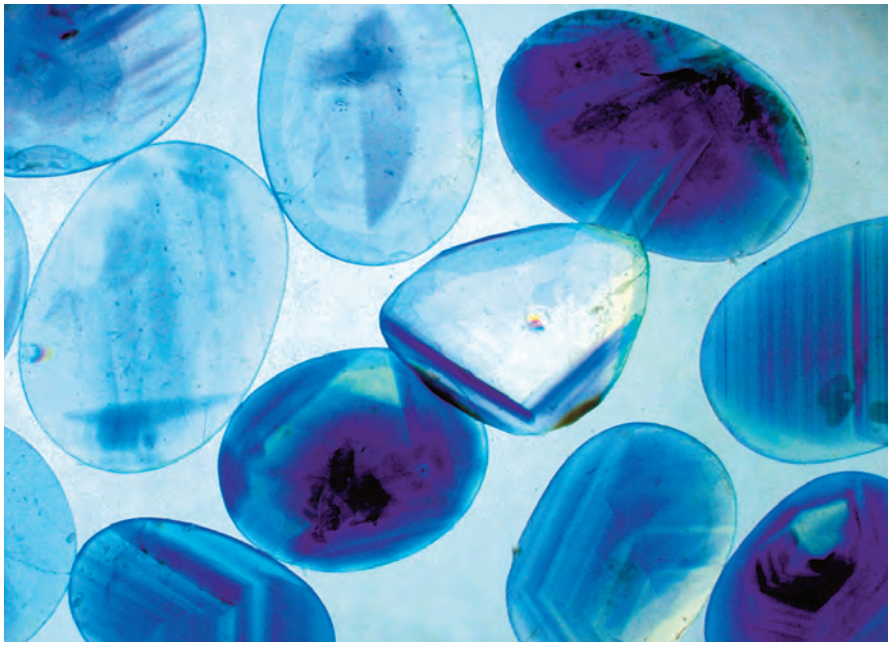
One gem crystal might have many generations of inclusions. It might contain included mineral crystals inherited from the surrounding rocks or feathers and fingerprints formed before growth stopped. It might also have fresh, unhealed fractures.

Other minerals might coat a gem's fractures long after the gem has formed. An iron mineral, for example, often coats hollow tubes or open fractures in Vietnamese rubies. You'll learn more about the different types of inclusions and how they affect gemstone appearance and value in Assignment 10.

Trace Elements

As a crystal grows, some chemical elements that aren't necessary for its growth can become trapped in its crystal structure. Since they're present at the atomic level, they're not considered inclusions. They're called *trace elements*, and they can affect a gem's appearance in many ways.

Trace elements—Atoms in a gem that aren't part of its essential chemical composition.

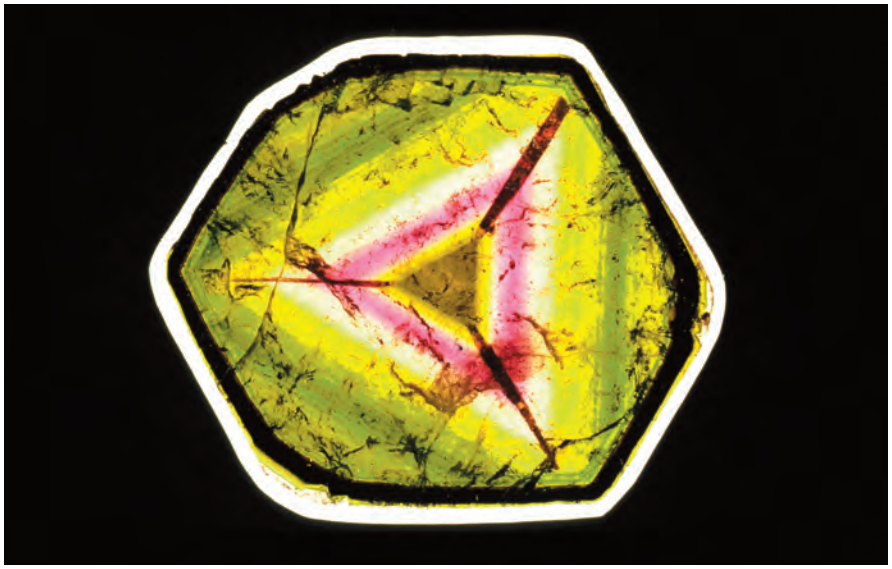


Alan Jobbins

Bands in these blue sapphires follow the original crystal faces, which were removed by the cutting process. Gemologists can determine the original crystal shape of these sapphires by looking at their color zones. Each band represents a change in the concentration of color-causing trace elements as the crystals grew.

Tino Hammid/GIA

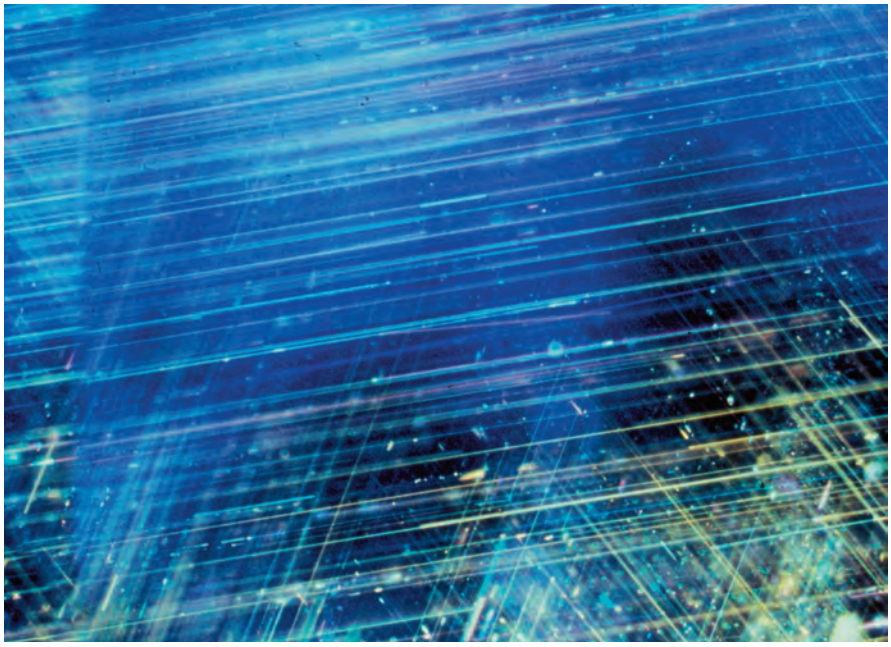
Tourmaline is the color-zoned gem that's most frequently used in jewelry. Here, a slender pink-green bicolor stone is mounted in a custom setting.



A. Ruppenthal KG

A slice through a tourmaline crystal from Madagascar reveals changes in coloring agents during growth. It also shows a change in shape, or habit, from its triangular cross-section—defined by the pink zoning at the center—to its final six-sided outline.

For example, iron and titanium aren't part of the essential chemistry of sapphire, which is composed of aluminum and oxygen. Iron and titanium are trace elements, and when the right amounts of them are trapped within sapphire's crystal structure, they cause the sapphire's blue color.



Rolf Schwieger

Rutile needles create a delicate pattern inside a Sri Lankan sapphire. As the sapphire cooled, titanium and oxygen were squeezed out of its crystal structure to form these delicate needles. (25X)

As a gem grows, the quantities of the trace elements within it can change. If that happens, it can lead to color zoning or even changes in the color of the entire gem.

If they're not already incorporated during growth, the atoms of a trace element might enter the crystal lattice later. This requires high temperatures because the energy provided by heat causes the trace elements to migrate into the crystal lattice. The high temperatures can exist during formation or they can be introduced by heat treatments used to improve color or clarity.

As the crystal cools, trace elements might stay trapped in the crystal lattice. If there's not enough room for them in the cooling crystal's structure, they're forced out. This can lead to the formation of inclusions.

One example of this process is the way rutile needle inclusions form in sapphire. As you've already learned, sapphire's essential ingredients are aluminum and oxygen, but it can also contain the trace elements iron and titanium. As long as temperatures are high, the titanium stays dispersed within the sapphire's crystal structure.

As the crystal cools, excess titanium and oxygen cannot be accommodated in the sapphire's crystal lattice so they combine to form rutile. The rutile forms fine needles, called "silk." The needles are aligned parallel to the sapphire's crystal directions. If enough needles are present, they might give rise to a six-rayed star.

Maha Tannous/GIA

Many of these crystals from alluvial gravels in Tunduru, Tanzania, are little more than rolled pebbles. Their original crystal faces were worn away during water transport. Crystals without obvious crystal faces are described as anhedral.

KEY CONCEPTS

Many rough gemstones have recognizable crystal shapes that can help identify them.

Habit—The characteristic external crystal shape or form of a mineral.

Recognizing Rough Gems

A still-intact crystal shape provides an important clue to a rough gem's identity. But even crystals that are broken or worn down by tumbling in a harsh alluvial environment might retain some of the crystal surface that can identify them.

Each rough gem has a characteristic shape or range of possible crystal shapes depending on the conditions it grows under. This characteristic shape is called its *habit*. It results from an interaction between the growing crystal and its environment.

Shape can help you tell rough ruby from rough spinel, and either one from rough red garnet or tourmaline. These clues are extremely valuable to people who buy and sell rough gems for a living. Knowledge of rough helps them avoid costly mistakes because they know that not every red gem is a ruby. (As you'll learn in Assignment 5, dishonest traders sometimes create copies of rough gem shapes and try to sell them as authentic gem rough.)

Knowledge of rough also alerts a buyer to a rough gem material's potential. Knowing that many rough rubies occur as flattened crystals helps a buyer understand why so many cut rubies have shallow proportions.

How Rough Dictates Finished Shape

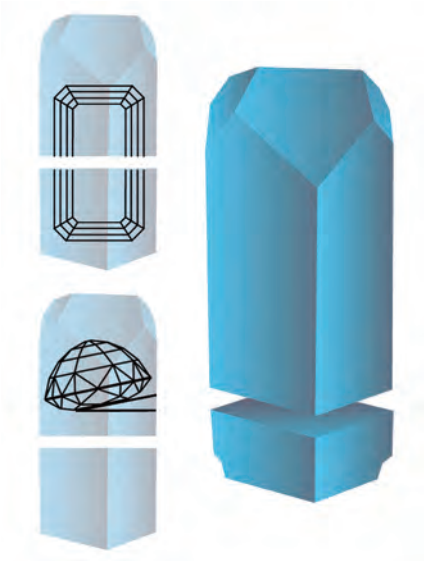
The gem cutter (lapidary) examines a rough tanzanite while rotating it. Will the rough yield one big stone or many smaller ones? Which is the best face-up direction for the best color? Which choice will bring the most profit?

The choices a lapidary makes at this stage will have the greatest impact on the way the finished stone will look, but the lapidary is limited in those choices by what nature provides.

The shape of the rough dictates the shape of the cut gem. In the individual stone assignments, you'll learn how the shapes of many gem crystals strongly influence the proportions of the faceted stones you'll see in the colored stone trade.

For instance, topaz crystals are often long and thin. To retain weight the lapidary might cut long, thin ovals or elongated rectangular step cuts. For every well-proportioned imperial topaz you'll see, there will be 10 or more long, thin ovals or pears.

Inner structure can also influence cutting decisions. Because of topaz's tendency to break parallel to the base of the crystal, stones are very vulnerable to knocks, or even the pressure of setting. This can make these attractive stones difficult to use and difficult to set. To make up for this weakness and minimize breakage during fashioning, the cutter tries to orient a topaz's table facet at a slight angle.



Peter Johnston/GIA

A topaz crystal's inner structure dictates the way it's cut. Because its cleavage plane is parallel to its base, long slender stones cut along the length of the crystal might break if handled roughly. Also, cutting parallel to the cleavage plane might cause small fragments of the crystal to break off during faceting. Cutters try to orient the table facet at a slight angle to the cleavage plane to minimize problems during faceting.

Eric Welch/GIA, courtesy Dr. Wagner Colombarolli

Robert Weldon/GIA, courtesy Pala International

Crystals of imperial topaz (above) are typically long and slender, limiting the shapes of the stones that can be cut from them. The cushion-cut, 5.40-ct. imperial topaz (right) retains the long slender form of the original crystal.

KEY CONCEPTS

The shapes and sizes of rough gem crystals affect the shapes and sizes of finished stones.

Vincent Pardieu/GIA

A buyer at a Mogok, Myanmar, gem market examines rough spinel crystals, whose characteristic octahedral shapes help separate them from other red gems like corundum and garnet.

Shane McClure/GIA

The external form or habit of a crystal is made up of a collection of various crystal faces. The number, size, and arrangement of these faces affect the crystal's overall shape significantly. These crystals show the different habits of sapphire. The crystal on the right is short and squat (tabular), and made up of six equal faces that form a prism. The crystal on the left lacks prism faces, but is composed of two six-sided pyramids joined back-to-back. This forms a bipyramid.

Recognizing Rough's Hidden Structure

It's 100 degrees in the shade. Under a makeshift sunscreen, a skilled buyer of gemstone rough scans a parcel of rough gems while the seller looks on nervously. Some stones are little more than rounded pebbles, while others have the sharp faces of fresh crystals. The buyer's trained eyes look for crystal shape or the characteristic surface markings that many gem crystals have.

Finally, the buyer makes a selection and agrees on a price. Everyone relaxes, and they seal the deal with a handshake. It could be Madagascar in the late 1990s, Vietnam in the 1980s, or Thailand in the 1970s: The same scene is repeated wherever gems are mined and bought or sold.

Gem buyers can confidently select rough gems because they know that even rolled pebbles of gem material retain their inner crystalline structure and order. The language used by many of them describes the gem crystals they see. You might also see these terms in gemological textbooks and in GIA's own gemological journal, *Gems & Gemology*.

Tabular: Squat and flat, like many corundum crystals.

Prism or prismatic: Columnar, with 3, 4, 6, 8, or 12 parallel faces. Many aquamarine and tourmaline crystals are prismatic.

Euhedral (Yoo-HEE-dral): Well formed, with sharp crystal faces, like most gems from pegmatite pockets.

Anhedral (Ann-HEE-dral): Lacking obvious crystal faces, like many gems that have been tumbled in rivers.

Striations: Horizontal (quartz, corundum) or vertical (tourmaline, topaz) growth markings on a crystal.

Pyramid: Shape with equal triangular faces that meet in a point.

Bipyramid: Shape with two pyramids back-to-back. Seen in sapphires, for example.

Peter Johnston/GIA

Most important commercial gems can be identified by their individual crystal shapes. This illustration shows a selection of actual rough gems, together with drawings of idealized versions along the outside edge.

1. Squat, flattened crystals with triangular surface features on the top surface are characteristic of ruby.
2. Sapphire crystals typically have two sets of six triangular faces joined back-to-back. Their linear markings run horizontally across the crystal faces.
3. Star-shaped chrysoberyl twins are common in the gem gravels of Brazil.
4. Imperial topaz crystals have a diamond-shaped cross-section, vertically grooved sides, and a chisel-shaped top.
5. Spinel often occurs as well-formed eight-sided (octahedral) crystals. They're common in the gem gravel of Mogok, Myanmar.
6. Garnet occurs as 12-sided (dodecahedral) crystals. Most garnet crystals in gem gravel have been worn to a rounded ball-like shape.

Jeffrey Scovil, courtesy Carl Larson Collection

Because of its exceptionally well-defined crystal faces, this 4.80-cm topaz from Mogok, Myanmar, would be described as euhedral.

Joel Beeson/GIA

These gems appear similar in size, but the aquamarine (left) weighs 20.01 cts. and the topaz (right) weighs 26.37 cts. This is because aquamarine's specific gravity is less (2.70) than topaz's (3.60). SG differences are caused by differences in the type and packing of the atoms that build each gem.

Physical Properties

- Why do different colored stones with similar dimensions have such different carat weights?
- How do physical properties affect a gem's durability?
- What's the difference between hardness and toughness?
- What are the different ways a gem can break?

As you learned in Assignment 2, some gems are able to endure the extreme forces of erosion. Those same qualities that allow gems to endure pounding in rivers and the stresses of mining make them ideal as tough, durable centerpieces of practical jewelry.

A gem's properties are a direct result of its crystalline nature. The types of atoms and the strength of the bonds between them determine not only its physical properties, but—as you'll learn in the next assignment—its optical properties as well.

Density and Specific Gravity

Density—How heavy an object is in relation to its size.

Specific gravity (SG)—Ratio of the weight of a material to the weight of an equal volume of water.

A 7×5-mm oval amethyst and a 7×5-mm oval zircon, sapphire, or diamond have the same measurements, but the amethyst weighs a lot less than the others. A 10-ct. aquamarine needs a larger mounting than a 10-ct. ruby of the same shape. This relationship between the heaviness of an object and its size is known as *density*.

Density can be measured by comparing the weight of the gem with an equal volume of water. This results in a ratio known as *specific gravity* (abbreviated SG). SG can be a helpful identifier for all gemstones. You'll learn how to calculate a gemstone's SG in GIA's *Gem Identification* course. There are also published references that list the SGs of a variety of gem materials.

SG is listed as a number. Amethyst's SG is 2.65; zircon's can range up to 4.70. The number tells you how much a mineral weighs compared with the same volume of water. This means that amethyst is just over 2½ times as heavy as the same volume of water. Zircon is nearly 5 times as heavy as an equal volume of water.

There's a difference in the way each of these gems is put together at the atomic level. Amethyst is made up of silicon and oxygen. Zircon, in addition to silicon and oxygen, contains atoms of zirconium, which makes it much heavier than amethyst.

KEY CONCEPTS

A gem's density and specific gravity depend on the types of atoms it's made of, and how closely they're packed together.

You can't always explain differences in gemstone density by judging how heavy their component elements are. Diamond, for example, is made only of carbon, which is one of the lighter elements. But diamond's specific gravity is greater than that of quartz, which is made of two heavier elements: silicon and oxygen.

There are two reasons for this. First, the high pressures of diamond formation press the carbon atoms tightly together. Second, very strong chemical bonds between the carbon atoms hold them there. The net result is simply that more atoms are packed into the same amount of space. So density isn't just affected by the type of atoms. How they're packed matters, too.

Durability

What qualities does sapphire possess that make it such a good ring stone? First, it's hard enough to take a good polish and keep it through a lifetime of wear. The lasting quality of sapphire's polish and luster are directly related to how well the stone resists scratching. Also, there are no serious weakness directions in most transparent gem-quality sapphires that would leave them vulnerable to unexpected damage. Sapphire is also chemically resistant, and the fine blue color won't fade when it's exposed to light. The ability of sapphire to withstand wear, heat, and chemicals is all part of its *durability*: a combination of hardness, toughness, and stability.

John Parrish

This ring features a 10.02-ct. blue sapphire from Madagascar, set in an 18K yellow gold and platinum custom mounting with 1.24 cts. of diamonds. Its beauty and durability will make it a treasured heirloom for generations to come.

Hardness

Hardness is a gem's resistance to scratches and abrasion. As you will learn later, it's usually expressed in terms of the Mohs scale. On the Mohs scale, diamond is the hardest, at 10, and talc is the softest, at 1.

A gem crystal's hardness is directly related to the strength of the chemical bonds between its atoms. In general, the stronger the bonds, the harder the crystal. When cut, a hard stone takes a better polish than a soft one. A hard stone like sapphire, for example, has sharper facet edges and a better quality surface reflection than a softer one like peridot.

Quartz, with a hardness of 7, has an important place in the gem hardness scale. This is because most of the dust in the air is composed of quartz. Eventually, a cleaning cloth becomes impregnated with dust. The simple act of wiping a soft stone like chrome diopside can damage its surface and dull its polish.

Factors other than hardness can determine how obvious a scratch on a gem will be. Scratches show up more on faceted stones than on cabochon-cut gems like opal, moonstone, and turquoise.

Tino Hammid/GIA

Although zircon has a hardness of 7.5, it is brittle, especially after heat treatment. Zircons stored together in a stone paper without some form of protection quickly abrade each other.

Toughness

Although hardness and *toughness* seem identical in everyday usage, in a gemological sense they have very different meanings. While hardness is resistance to scratching, toughness is resistance to breaking and chipping.

To visualize the difference, consider the difference between glass and leather. You can't scratch glass with your fingernail, but a sharp blow will shatter it. A fingernail can scratch leather, but you can exert forces on a thin piece of leather that would easily crack glass of the same thickness. Glass is hard but brittle. Leather is soft but tough.

Although single-crystal topaz is a relatively hard stone, it's brittle. A sharp blow can chip or crack it. Aggregates like jadeite or nephrite, while softer than topaz, consist of a multitude of interlocking crystals, making them far tougher. Jadeite and nephrite are more resistant to knocks or abrasions than transparent colored stones.

Durability—A gemstone's ability to withstand wear, heat, and chemicals.

Hardness—How well a gemstone resists scratches and abrasion.

Toughness—How well a gemstone resists breaking and chipping.

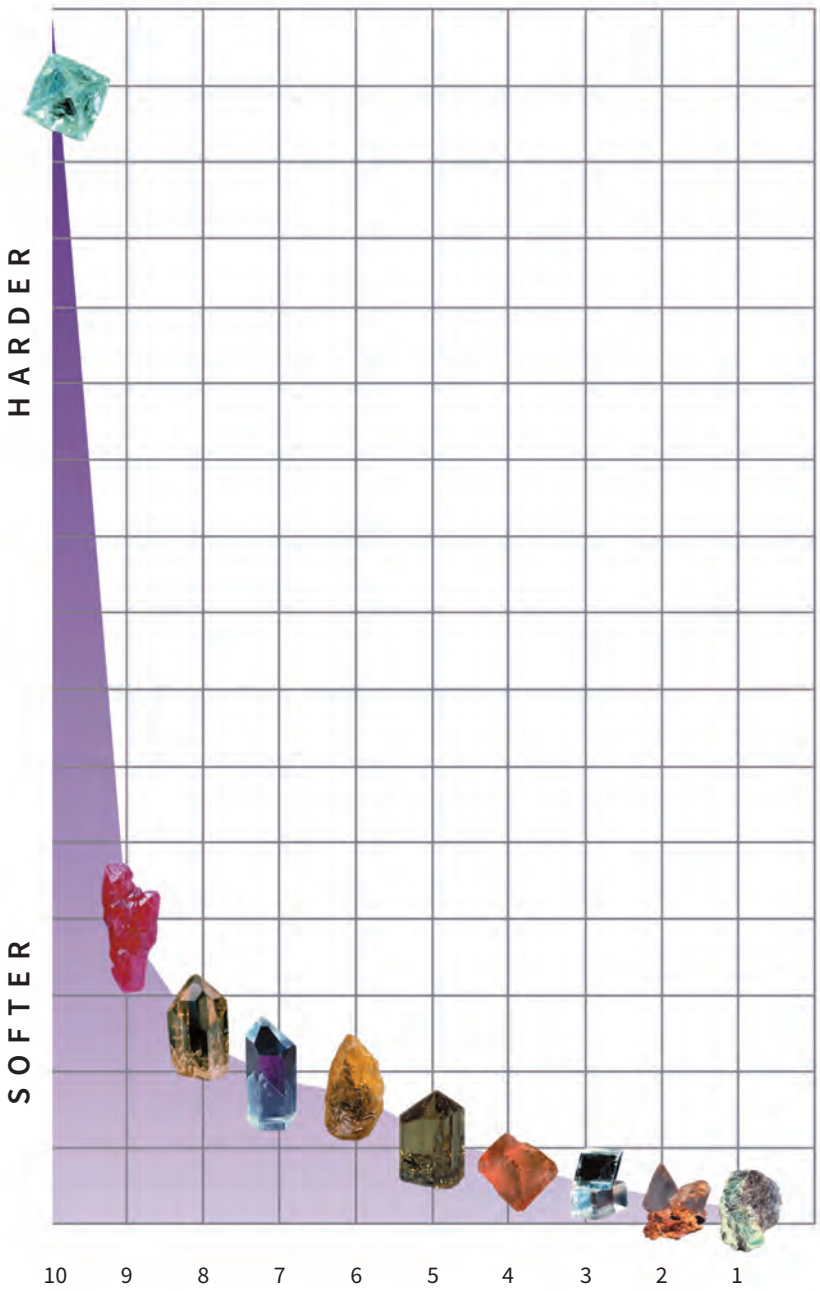
What the Mohs Scale Means for Gems in Jewelry

In 1822 a German professor and mineralogist named Friedrich Mohs (MOZE) developed a system for rating the relative hardness of minerals. Because diamond scratched every other mineral, he gave it the number 10. He then tested other minerals in a similar way and came up with what's known as the Mohs scale.

Without knowing anything else about the minerals on the list, you might think diamond is only a little harder than corundum, but as you can see from the illustration, the steps between the minerals on the scale don't represent uniform differences in hardness. They merely represent an order of relative hardness. Each mineral can scratch the ones below it on the scale.

For a gem, hardness equals permanence. A gem's hardness has important consequences for the way it's used. Listed below are hardness rankings for the common commercial gems:

- Diamond has a hardness of 10. It's harder than any other gemstone.
- Ruby and sapphire have a hardness of 9 on the Mohs scale, and make excellent ring stones.
- Chrysoberyl, topaz, spinel, emerald, and aquamarine have a hardness between 7.5 and 8.5 and make very good ring stones. (Topaz and emerald have other durability challenges: topaz due to cleavage, emerald due to inclusions and treatments.)
- Tourmaline, tsavorite, red garnet, iolite, amethyst, and zircon have a hardness between 7 and 7.5, and make good ring stones. (Most dust in the atmosphere is quartz, with a hardness of 7. Gems below 7 on the Mohs scale will suffer abrasion during cleaning and wear.)
- Kunzite, demantoid garnet, peridot, and tanzanite have a hardness between 6.5 and 7. They're best suited for items such as pins, earrings, and pendants, where they won't be so exposed to damaging situations. When mounted in rings, these stones require care when worn.
- Nephrite and jadeite have a hardness between 6 and 7. In spite of this, they make good ring stones. This is because their aggregate structure makes them extremely tough—especially important for men's jewelry. Chalcedony, with a hardness of 6.5 to 7, is also tough for the same reason.
- Feldspar, diopside, and non-phenomenal fire opal have a hardness between 5 and 6.5, and are best suited for items such as earrings and pendants, or occasional wear.
- Rhodonite, turquoise, opal, and lapis lazuli have a hardness between 5 and 6, and are best suited for items such as earrings and pendants. Wear is less visible on these stones because of their lack of transparency and the way they are cut.
- Pearl, rhodochrosite, malachite, coral, amber, and ivory rate between 2 and 4.5 on the Mohs scale. They're best suited for items such as pins, earrings, and pendants, or for use as decorative objects. These gem materials can be damaged or discolored by chemicals or application of heat that would leave most other gems unharmed.



MOHS SCALE
(top to bottom)

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

Renee Moore/GIA

The thin shell of this mabé—an assembled cultured blister pearl—was cracked by a sharp blow, exposing the layers inside. Thin-skinned cultured pearl products require care in wear, and are better suited for brooches, pendants, and earrings than rings.

Toughness is described as exceptional (jadeite and nephrite), excellent (corundum), good (quartz and spinel), fair (tourmaline), or poor (feldspar and topaz).

Perhaps the most important component of toughness is the way a gem reacts to stress when it breaks. The different ways a gem breaks are called cleavage, parting, and fracture.

Cleavage, Parting, and Fracture

The strength of a crystal is directly related to the strength of the bonds that bind its atoms together. A rough gem is exposed to external stress when it's tumbled in a mountain stream and during mining operations; a finished gem, when it's cut and polished, or during wear in jewelry. Depending on its crystal structure, a gem reacts to stress in different ways.

If the crystal's structure has weaker bonds or fewer bonds in certain directions, then stress will cause breaks in those directions first. If you strike a faceted tanzanite or kunzite sharply, it might break along planes determined by the gem's atomic structure. This type of break is called *cleavage*, and the weaker directions are called cleavage planes.

Cleavage—A smooth, flat break in a gemstone parallel to planes of atomic weakness, caused by weak or fewer bonds between atoms, or both.

Cleavage is a smooth, flat break in a gemstone parallel to its cleavage planes. Because a gem has many parallel cleavage planes, broken surfaces might have a step-like appearance.

KEY CONCEPTS

The different ways a gem breaks are called cleavage, parting, and fracture.

A gem's crystal structure determines its reaction to external stress.

Joel Beeson/GIA

The flat surface on the top of this topaz crystal is a cleavage plane. It's a weaker direction in the crystal's structure where stress caused it to break cleanly.

"Cleavage" also refers to the property of a gem that allows the break to occur. Cleavage is part of a mineral's structure. Each and every example of that mineral has the same hidden weakness. For instance, in diamond, the chemical bonds between individual carbon atoms are all the same type and strength, but in cleavage directions there are simply fewer bonds.

Bonding forces in gems like tanzanite, topaz, feldspar, diopside, and spodumene are significantly less in some directions than in others. Too much pressure will cause the crystal to split along the line of least resistance. Because of such structural weaknesses, these gems require care in cutting and handling.

Not all gems are subject to cleavage, and many of those that are can be used safely in jewelry if you protect them from unnecessary exposure to wear. Gems with cleavage need well-designed mountings to protect them during regular wear. Mountings that protect a gem's corners and points provide the best protection. Remember that jewelry items such as pendants, earrings, and pins are less exposed to wear than rings and bracelets.

Sometimes a rough ruby or sapphire crystal has three sets of parallel lines aligned with certain crystal faces. These lines of weakness are associated with twinning, a common feature of both. The crystal might break along these lines if it's subjected to enough pressure. This is described as *parting*.

Parting is different from cleavage. Parting is a flat break caused by heavy concentrations of included minerals, which may be associated with twinning planes. Cleavage, on the other hand, is caused by a gem's own atomic structure.

If you examine enough faceted rubies and sapphires with a microscope, you'll notice that thin needles (composed of an aluminum mineral called boehmite) are associated with twinning planes. These needles grow during twinning when the crystal is subjected to pressure. If enough boehmite needles are concentrated along the twinning planes, this creates weak areas where there is less corundum present than elsewhere. If the crystal is stressed along these inclusion-rich layers, this is where it will break.

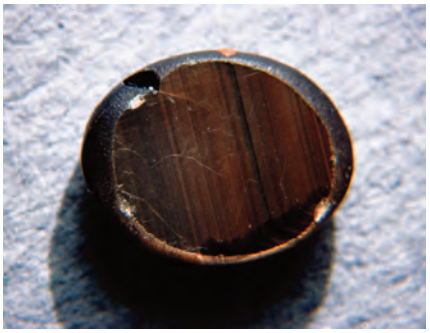
Parting is most common in very highly twinned or included crystals that are used for cabochons or beads. These stones rarely achieve a good polish because tiny fragments of the crystal are pulled out during polishing.

If a gem doesn't have planes of weakness like cleavage or parting, the pattern of breakage is different. The term *fracture* is used to describe a break in a gem other than cleavage or parting.

The most common type of fracture in transparent gems yields a characteristic surface pattern of concave ridges, like a clamshell. This type of fracture is called *conchoidal fracture*, and it occurs in glass as well as in quartz, opal, peridot, and many other colored gems.

John Parrish/AGTA

A carefully designed setting protects the edges of this 5.50-ct. champagne-colored topaz against accidental damage.

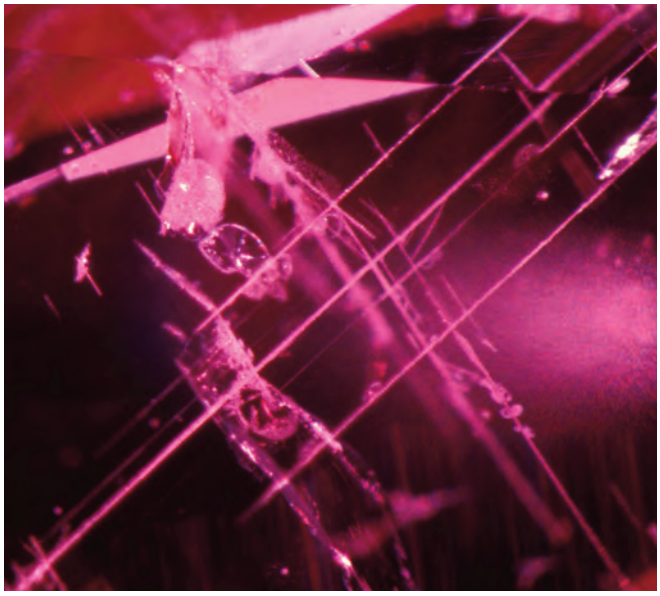


The back of this black star sapphire cabochon shows damage from parting. Heavy concentrations of hematite platelets oriented along crystal directions cause both the star effect and weaknesses in the stone. If struck, the gem is likely to break in directions where the inclusions are concentrated.

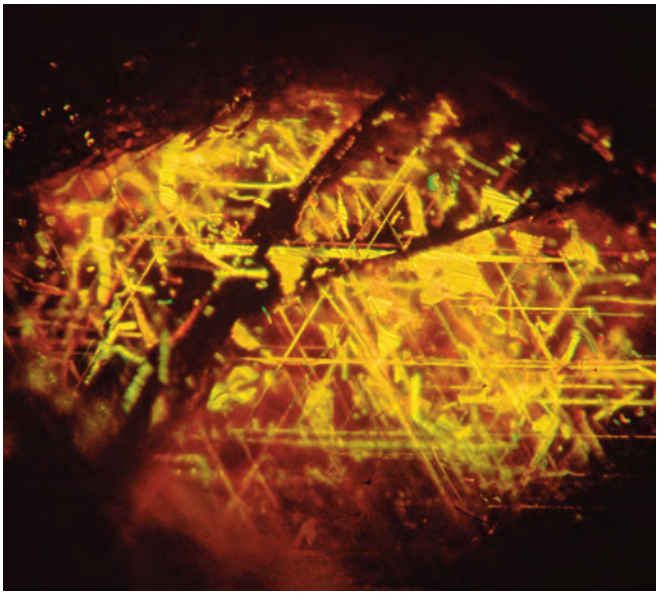
Parting—A flat break in a gemstone caused by concentrated included minerals parallel to a twinning plane.

Fracture—Any break in a gem other than cleavage or parting.

Conchoidal fracture—A curved and ridged fracture in a gemstone, extending from the surface inward.

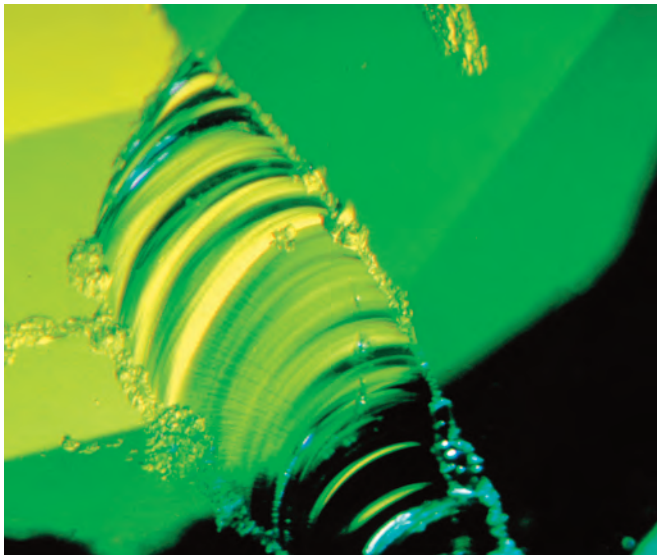


John Koivula/GIA



Jaroslav Hyrsl

In corundum, twinning is often accompanied by the formation of boehmite needles parallel to the twinning planes (left). Concentrations of these inclusions can cause weaknesses in a stone's structure. If the stone is struck, it might break along these layers in an effect called parting. Hematite inclusions, which appear as brownish flakes or needles in this sapphire cabochon (right), also create the potential for parting.



Alan Jobbins

Tino Hammid/GIA

Curved shell-like surfaces are typical of a conchoidal fracture (left). Many gem materials, including peridot, garnet, quartz, glass, and opal, might show this type of fracture surface. Nephrite (right) is a tough aggregate with a granular, or sometimes splintery, fracture surface. It looks like this because the surface is actually a multitude of broken crystals.

Jade's structure of tiny interlocking crystals gives its fractures a granular surface appearance, because the breaks occur within or between individual crystals. Rocks like lapis lazuli also have a granular fracture surface because they're made up of a mixture of different minerals, each of which reacts differently to stress.

Cracks in gem-quality opal—called crazing—are probably a result of water loss from the gem's structure over the course of time. Relatively few opals craze like this.

Robert Kane/GIA

Peridot is a gem that's susceptible to etching by certain chemicals. Chemicals used during jewelry repair damaged the surfaces of this peridot.

Stability

A gem's ability to tolerate the effects of light, changes in temperature, or the action of chemicals is called *stability*. Gems with poor stability, including many treated gems, require extra care in wear and cleaning.

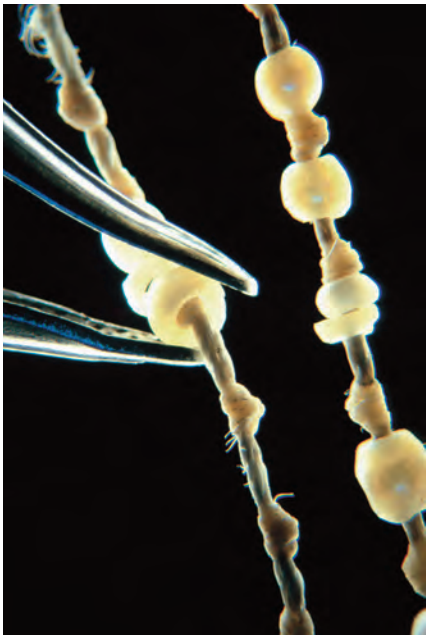
Gem-quality opal contains a small percentage of water in its structure, so if an opal is exposed to the intense glare of showcase lights for any length of time, the heat will cause dehydration. This might cause the opal to crack. A sapphire can endure the same conditions without ill effects. Weak acids easily damage gems like pearl, coral, and rhodochrosite. Even skin oils can damage pearls over time.

Peridot, tourmaline, tanzanite, and some garnets react poorly to sudden changes of temperature. Fractures can result from the careless application of a jeweler's torch during repair procedures. Damage of this type is described as *thermal shock*. It can occur when the temperature change is from hot to cold or from cold to hot.

As you've learned, a gem's crystal structure has a great deal to do with how it looks, how it's cut, and how it reacts to stress. In the next assignment, you'll learn how crystal structure affects a gem's optical properties—the way it interacts with light.

This assignment and the next one should help you as you progress through the rest of the course. In the treatments assignment, you'll learn about fissure filling, irradiation, and other treatments that solve some of the challenges presented by an individual gem's structure—but create some challenges of their own. And in the individual gemstone assignments, you'll find more detail about which gems need special care in cutting and wear—largely because of their structures and properties.

You probably won't have to relate the science of crystal structure in your everyday dealings, but this knowledge should add to your understanding of all the gems you handle. No matter what your place in the gem industry, this is a valuable benefit.



Rene Moore/GIA

Time, extreme wear, and exposure to skin acids have destroyed this string of pearls.

Stability—How well a gemstone resists light, heat, and chemicals.

Thermal shock—Damage caused by sudden, extreme temperature changes.

KEY CONCEPTS

Crystalline minerals are classified into seven crystal systems, depending on the symmetry of their unit cells.

The exterior shape of a crystal often indicates its symmetry at an atomic level.

Some gems are rare because they require rare chemical elements or unique geological conditions, or both, to form.

Twinning can result from a change during crystal growth, or from cooling or pressure after the crystal has grown.

Inclusions in a colored stone can help identify it as natural or manmade, untreated or treated.

Large inclusions can dramatically affect beauty, value, and durability.

Many rough gemstones have recognizable crystal shapes that can help identify them.

The shapes and sizes of rough gem crystals affect the shapes and sizes of finished stones.

A gem's density and specific gravity depend on the types of atoms it's made of, and how closely they're packed together.

The different ways a gem breaks are called cleavage, parting, and fracture.

A gem's crystal structure determines its reaction to external stress.

Key Terms

Aggregate—A mass of tiny, randomly oriented crystals.

Cleavage—A smooth, flat break in a gemstone parallel to planes of atomic weakness, caused by weak or fewer bonds between atoms, or both.

Conchoidal fracture—A curved and ridged fracture in a gemstone, extending from the surface inward.

Cryptocrystalline—An aggregate made up of individual crystals detectable only under very high magnification.

Density—How heavy an object is in relation to its size.

Durability—A gemstone's ability to withstand wear, heat, and chemicals.

Fracture—Any break in a gem other than cleavage or parting.

Habit—The characteristic external crystal shape or form of a mineral.

Hardness—How well a gemstone resists scratches and abrasion.

Inclusion—A characteristic enclosed within a gemstone or reaching its surface from the interior.

Liquid inclusion—Small pocket in a gem that's filled with fluids and, sometimes, gas bubbles and tiny crystals.

Microcrystalline—An aggregate made up of individual crystals visible under magnification.

Parting—A flat break in a gemstone caused by concentrated included minerals parallel to a twinning plane.

Specific gravity (SG)—Ratio of the weight of a material to the weight of an equal volume of water.

Stability—How well a gemstone resists light, heat, and chemicals.

Thermal shock—Damage caused by sudden, extreme temperature changes.

Three-phase inclusion—A hollow cavity in a gem filled with a liquid, a gas, and one or more crystals.

Toughness—How well a gemstone resists breaking and chipping.

Trace elements—Atoms in a gem that aren't part of its essential chemical composition.

Twinning—Change in a gem's crystal direction during or after growth.

Twinning plane—Location of a change in crystal growth direction.

Two-phase inclusion—A hollow cavity in a gem, usually filled with a liquid and a gas.

Unit cell—The smallest group of atoms with both the characteristic chemical composition and crystal structure of a mineral.

Questions for Review

- How does a rough crystal get its start?
- How do inclusions and trace elements become part of a gem?
- What features can help you recognize different rough gemstones?
- How does crystal shape affect the way a stone is cut?
- Why do different colored stones with similar dimensions have such different carat weights?
- How do physical properties affect a gem's durability?
- What's the difference between hardness and toughness?
- What are the different ways a gem can break?

Gems and Light

4

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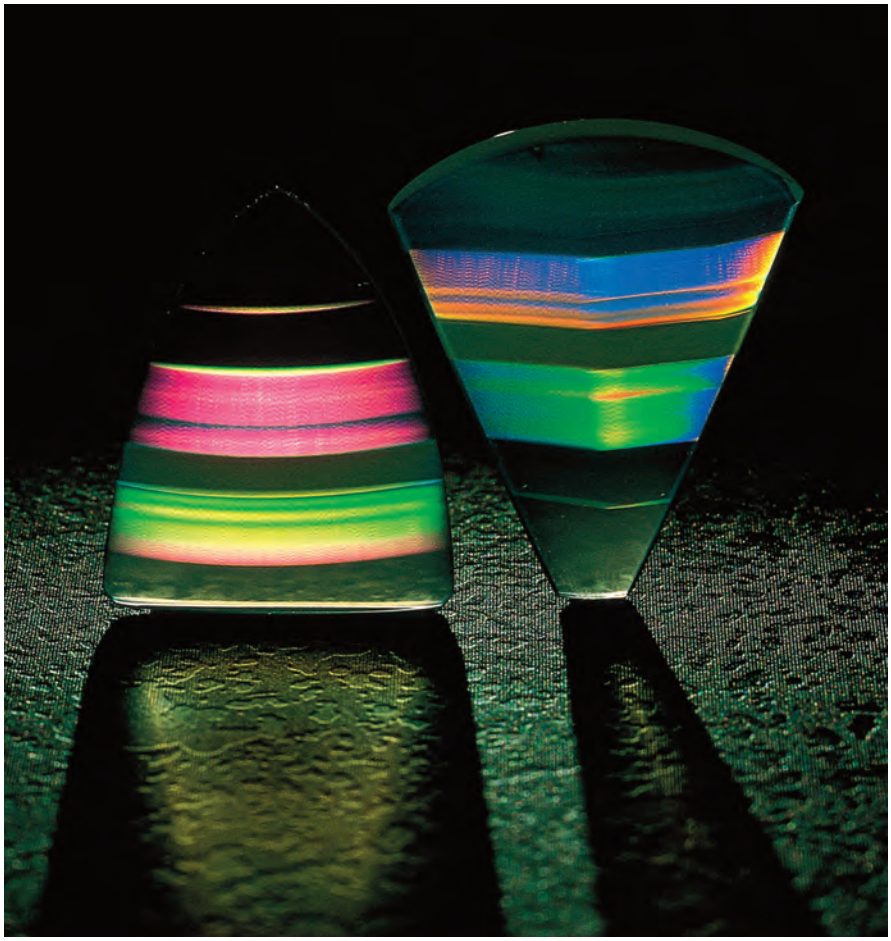
Welcome to *Colored Stones* Assignment 4. With the knowledge you gain from this assignment, you'll be able to:

- Describe how a gem's interaction with light influences its color.
- Understand why color range can differ from one gem variety to another.
- Explain how cut can make a difference in a gem's face-up appearance.
- Communicate the effect of crystal structure on a gem's color and phenomenon.
- Recognize the phenomena caused by the presence of inclusions.



Robert Weldon, courtesy Crystal Reflections

These agates display a striking appearance that arises from their direct interaction with light.

Gems and Light

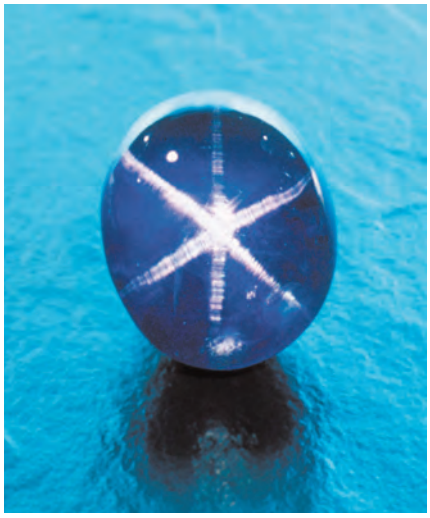
A proud owner shows off a beautiful sapphire cabochon. It's an exceptional gem with brilliant, nearly transparent blue color. Three intersecting bands of light form a sharp, well-centered star that sweeps across its domed surface.

The star's impact is greatly enhanced by the sapphire's striking deep blue color. In fact, while the star is an important part of the gem's appeal, it's really the color that gives this sapphire its value. This is true of all colored gemstones: The color, above almost any other factor, determines desirability and marketability.

Fine star sapphires are among the most rare and highly valued gems. Other gems with their own special effects include alexandrite, cat's-eye chrysoberyl, and opal. To assess them properly, it's important to know what causes their color and striking optical effects. And that means learning about the way these gems interact with light. This assignment will cover the basics of that interaction.

KEY CONCEPTS

Color is the most important contributing factor to a colored stone's desirability, marketability, and value.



Bart Curren/ICA

This 19.32-ct. Sri Lankan star sapphire displays an exceptional combination of color and phenomenon.

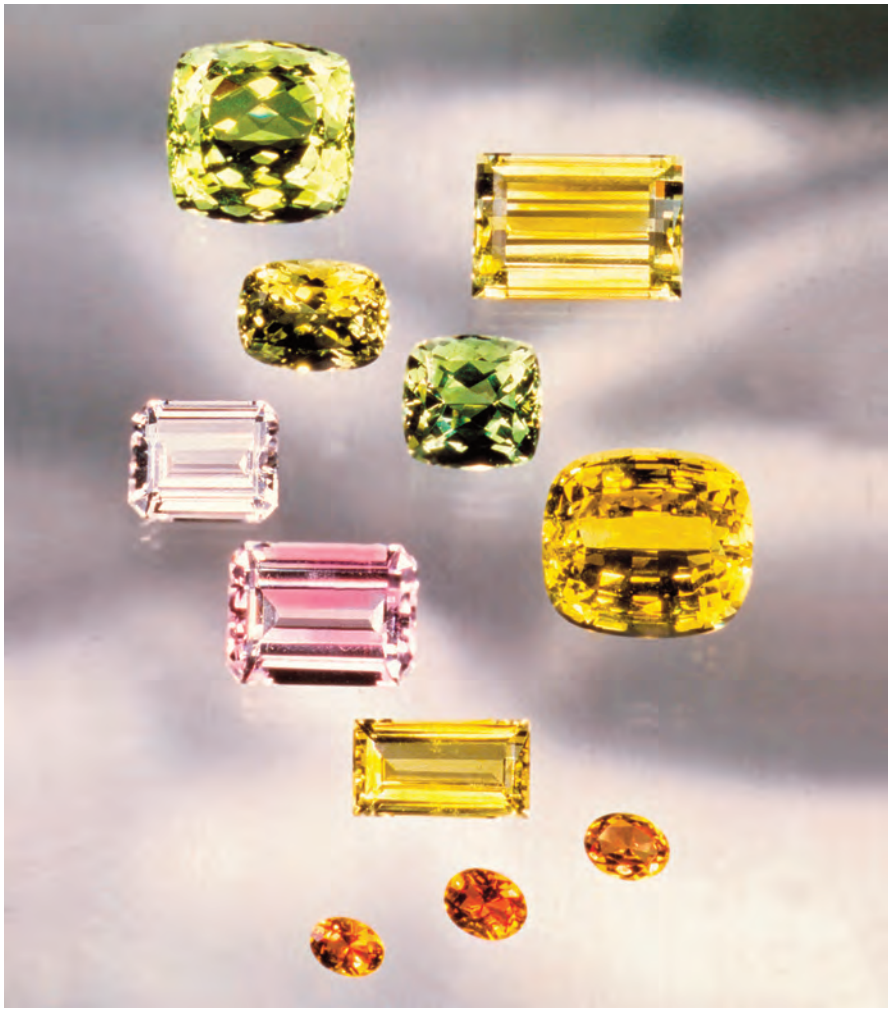
Tino Hammid/GIA

Fine cat's-eye and alexandrite chrysoberyl are among the rarest and most highly valued gems. The 5.47-ct. cat's-eye chrysoberyl and the 3.03-ct. alexandrite are both from Brazil.

You'll learn why some gems, like peridot and almandine garnet, occur only in certain colors, while others, like corundum, beryl, and tourmaline, are found in a wide range of different colors. You'll also learn why some gems from the same rough can show very different face-up colors when they're cut in different crystal directions.

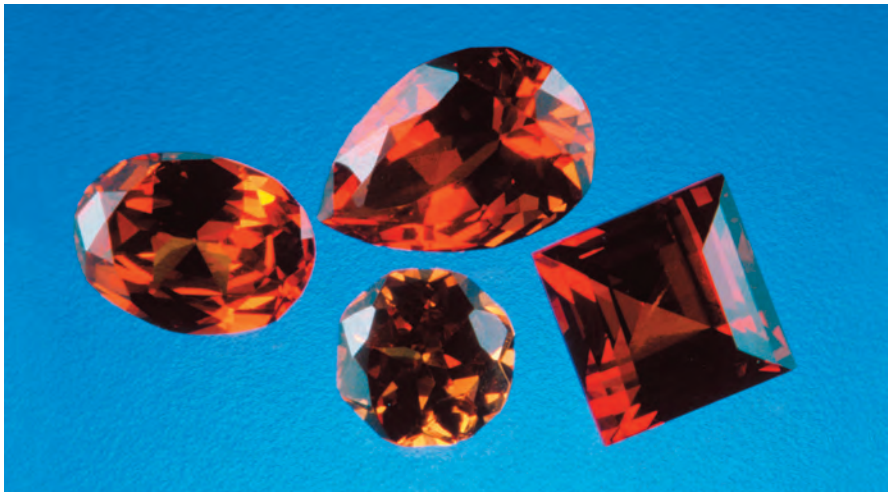
It's worth taking the time to understand how color happens in natural gems. It will help you understand how treatments—techniques like heating and irradiation—can make many natural gems more marketable. It'll also help you understand why, while some natural gems and their synthetic counterparts look almost identical, they sometimes get their color in very different ways.

After you learn the basics of the interaction between gems and light, assignments later in the course will provide more detail on individual gems and their unique properties, along with their places in the market.



A.Ruppenthal KG

Some gems have a wider color range than others. Beryl's range includes pinks, greens, yellows, and more.



Maha Tannous/GIA

Spessartine garnet's orange to orangy red color range is quite narrow.

How Gems and Light Interact

- Why are some gem colors more rare and more valuable than others?
- Which element produces the brightest reds and greens?
- How can the same impurity element cause different colors in different gems?
- How does a gem's interaction with light cause its color?

Many people consider the rich bluish green of fine emerald to be the most beautiful green in the gem world. The best green sapphire and peridot can't compare with it, but other gems, like tsavorite garnet and tourmaline, can get fairly close. These gems are all green, but each one owes its color to a different cause.

Ruby brings an intensity to red that gems like almandine garnet can never match. The color differences you see when you compare fine examples of both gems come down to the way each gem gets its color.

Tino Hammid/GIA, courtesy Chris Almquist

Tino Hammid/GIA, courtesy 23rd St. Shoppe, Santa Monica, CA

Tino Hammid/GIA, courtesy 23rd St. Shoppe, Santa Monica, CA

Robert Weldon/GIA, courtesy Frank Goodman & Son, Los Angeles, CA

There are many green gems, including tsavorite garnet (top left), green tourmaline (top right), and peridot (bottom left), but none of them match emerald's color (bottom right). Emerald can also surpass all other green colored stones in value.

Robert Weldon/GIA, courtesy Lewis Allen

Tino Hammid/GIA, courtesy Varujan Arslanyan

The superb 5.42-ct. Burmese ruby (left), with its vivid red color, is far rarer and much more valuable than the garnets (right), even though their size and overall quality are equivalent.

Tino Hammid/GIA

Robert Weldon/GIA, courtesy John Ng

Gems of the same species can look identical, but one might owe its color to treatment rather than nature. The rings (left) contain fine, naturally colored jade, but the assorted jade pieces (right) are dyed.

There are examples like these for every color of the rainbow: Gems that fall into the same color category, but range widely in the quality of their colors. And the color variations from gem to gem make real differences in value. The gems with the best colors are always more attractive, more rare, and more highly valued than the others. The causes of color are what make those color and value differences possible.

Causes of color can also help separate natural from synthetic gems. For example, inexpensive synthetic blue spinel and much more valuable natural aquamarine can look very similar. Yet each gem is colored in a different way. The difference allows trained gemologists to separate the synthetic stone from the natural one.

KEY CONCEPTS

Light is a form of radiant energy that travels in waves.

Visible light is a small portion of the electromagnetic spectrum.

Wavelength—The distance between two adjacent high points of an energy wave.

Similarly, some treated gems can be identified by cause of color. For instance, dyed green jadeite can be separated from natural green jadeite by the different way it interacts with light.

In each case, the differences in appearance and value result from the way the gem's structure or impurities in its structure absorb light.

The Nature of Light

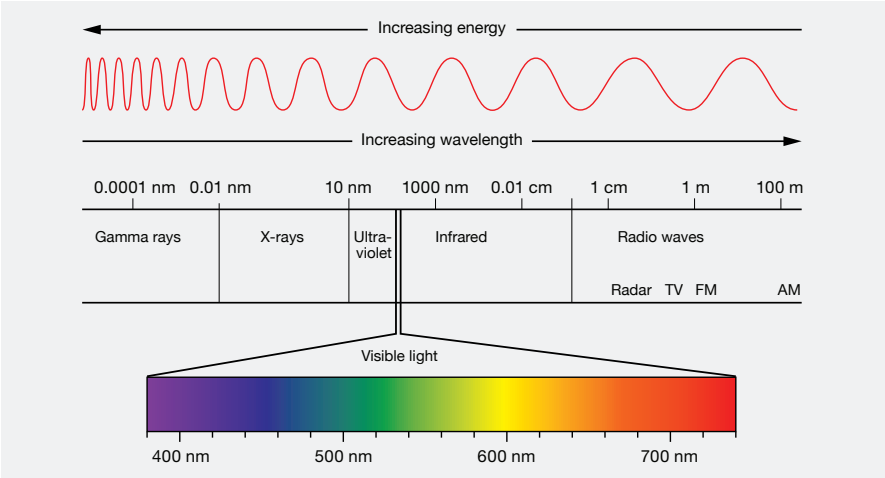
Gems and light interact in many ways. To understand their interaction, you need to know a few things about light itself. Visible light is a form of radiant energy, or radiation. It's a combination of electric and magnetic (electromagnetic) energies, and it travels in waves. All electromagnetic energy, including light, is measured in *wavelengths*. A wavelength is the distance between one high point and the next along an energy wave's path.

Wavelengths are measured in nanometers, abbreviated nm. A nanometer is tiny: One nm equals a millionth of a millimeter.

Light travels in a straight line from its source to an object and then bounces off the object to your eye. If the object is transparent, some of the light might also pass through it. Sometimes, the object and the source are the same—the sun, a glowing coal, or a light bulb—and the light goes directly from the source to your eye.

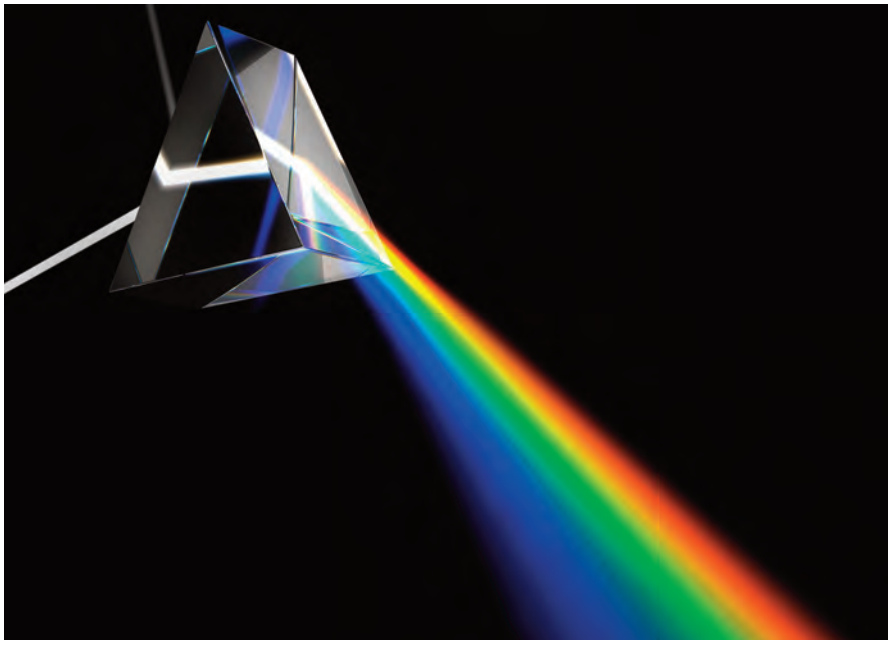
You can't see a beam of light unless it meets your eye or falls on an object. And you can see an object only if it scatters or reflects light. That's why a very clean window is almost invisible: The light passes through it without being reflected or scattered.

Visible light is a small portion of the electromagnetic spectrum, which also includes rays with shorter wavelengths and higher energy, like ultraviolet radiation and X-rays, and longer wavelengths and lower energy, like infrared radiation and radio waves. Visible light extends from about 400 nm (violet wavelengths) to about 700 nm (red wavelengths) in the spectrum.



Christopher Cruz/GIA

Visible light is a small portion of the electromagnetic spectrum. It's made up of the spectral color components of white light. The shorter wavelengths above the violet end of the visible range have higher energy than the longer wavelengths below the red end of the visible range.



Andrzej Wojcicki, courtesy Getty Images/Science Photo Library RF

White light consists of a rainbow of component colors that show up dramatically when the light passes through a prism.

KEY CONCEPTS

White light is a combination of the spectral colors red, orange, yellow, green, blue, and violet.

Most gem color is caused by selective absorption, which is influenced by chemical composition and crystal structure.

Although your eye sees the combined rays of the visible spectrum as white light, it's actually a combination of the spectral colors red, orange, yellow, green, blue, and violet. Each color represents lightwaves of different energies. White light is the sum of all these waves traveling together in the same direction.

Selective Absorption

A gemstone's color results from its interaction with visible light. For example, when white light strikes a transparent, faceted colored gem, some of it always reflects off the gem's surface. The rest enters the stone, where the gem's crystal structure absorbs some of the white light's color components. The remaining color components bounce off the gem's inner surfaces and return to your eye. The light you see as the gem's color represents the light that returned to your eye without being absorbed. This process is called *selective absorption*. It's influenced mostly by a gem's chemical composition and crystal structure.

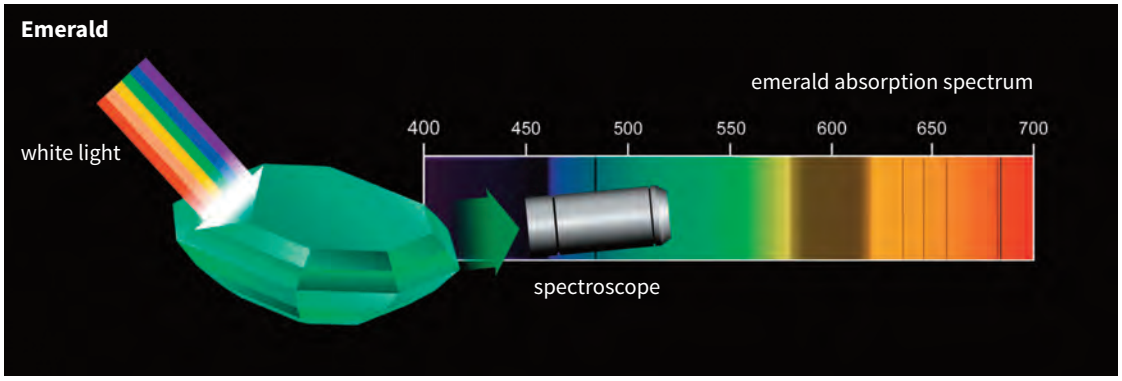
A simple instrument called a spectroscope helps gemologists use the principle of selective absorption to analyze gem color. The spectroscope splits light into its spectral colors. When you look through a spectroscope, the colors are displayed as a rectangular strip with red at one end and violet at the other.

If you place a gem in front of a light source and look at it through a spectroscope, you might see a pattern of dark lines and bands. The dark areas show which spectral colors the gem absorbs. Some gems can be identified by the pattern of dark areas that the spectroscope reveals. Gemologists describe this pattern as the gem's *absorption spectrum*.

Selective absorption—Process by which a material absorbs some components of visible light and transmits others.

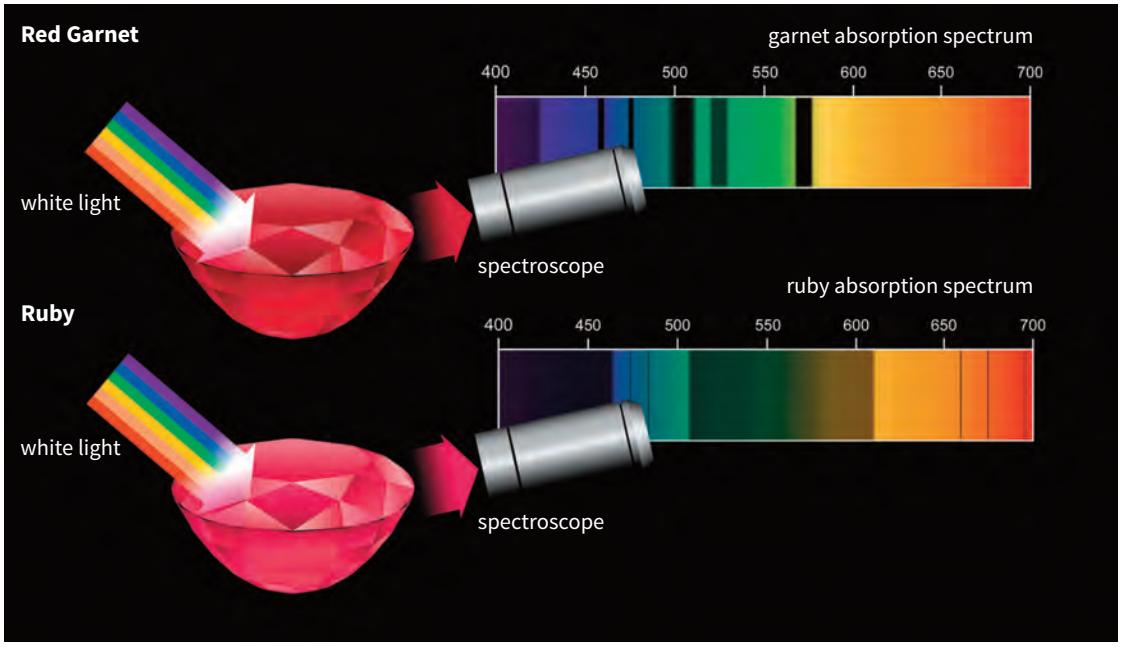
Absorption spectrum—A pattern of dark vertical lines or bands shown by certain gems when viewed through a spectroscope.

A spectroscope lets you see the distinctive patterns of light absorption that some gems produce. The spectroscope is the vertical black tube above the unit. A light in the base illuminates the gem.



Peter Johnston/GIA

Emerald's green color is a result of selective absorption. The gem absorbs violet, yellow, orange, and some red components of white light. The remaining unabsorbed light—mostly green and blue—returns to your eye as the gem's color.



Peter Johnston/GIA

Although red garnet and ruby look alike, they absorb light differently, so you can use the spectroscope to tell them apart. The spectroscope shows a distinctly different set of lines and bands for each gem.

For example, emerald absorbs light in a very distinctive way. The gem's absorption spectrum shows that it absorbs violet, yellow, orange, and many of the red components of visible light. The gem's characteristic bluish green color is a combination of the remaining blue and green components. You'll learn more about the spectroscope in the GIA *Gem Identification* course.

Atoms, Electrons, and Ions

Assignment 1 introduced you to the atom as the basic structural unit of all matter. Later, in Assignment 3, you learned that all materials are made up of chemical elements. Each element is composed of one kind of atom.

Scientists have refined their models of the atom over time, but the version introduced by physicists Niels Bohr and Ernest Rutherford in 1913 is still very useful. This model depicts the atom with a small central nucleus that contains even smaller particles called protons and neutrons. Protons carry a positive charge while neutrons are electrically neutral. An atom also contains negatively charged electrons.

In the Bohr model, the electrons travel around the nucleus in outer shells, also called orbitals. Because opposite charges attract, the protons in the nucleus act like magnets for the orbiting electrons. The attraction holds the electrons in the orbitals.

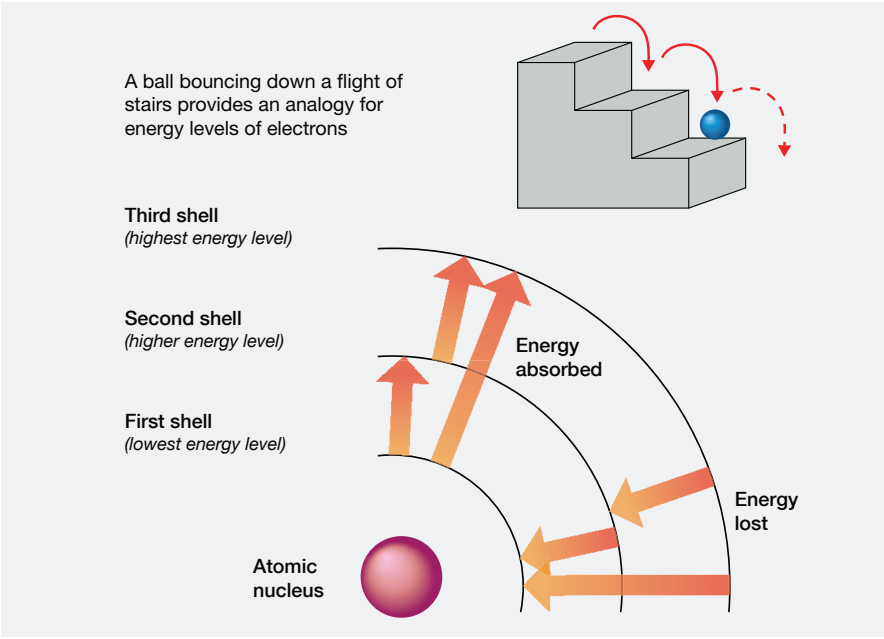
Electrons play an especially important role in selective absorption because visible light interacts mainly with them. Most of the gem colors caused by selective absorption are ultimately the result of the movement of electrons.

Every atom has an "ideal" number of electrons that is equal to the number of protons in its nucleus. If the numbers are the same, the atom is electrically neutral. When an atom loses or gains electrons, it becomes electrically charged—an ion. When it loses electrons, it's a positively charged ion—sometimes called a cation—while gaining electrons produces a negatively charged ion—an anion. The ion's electrical charge—its potential capacity for combining with other ions—is called its valence. The number of electrons above or below an ion's neutral state is called its valence state.

An electron is stable only at an energy level called its ground state. When an electron absorbs energy it rises temporarily to a higher-level so-called excited state. The movement from the ground state to the excited state is called a transition. To make a transition, the electron must absorb some of the energy it needs from visible light. The electron releases that energy when it returns to its ground state. A combination of the unabsorbed colored wavelengths results in the gem's color.

KEY CONCEPTS

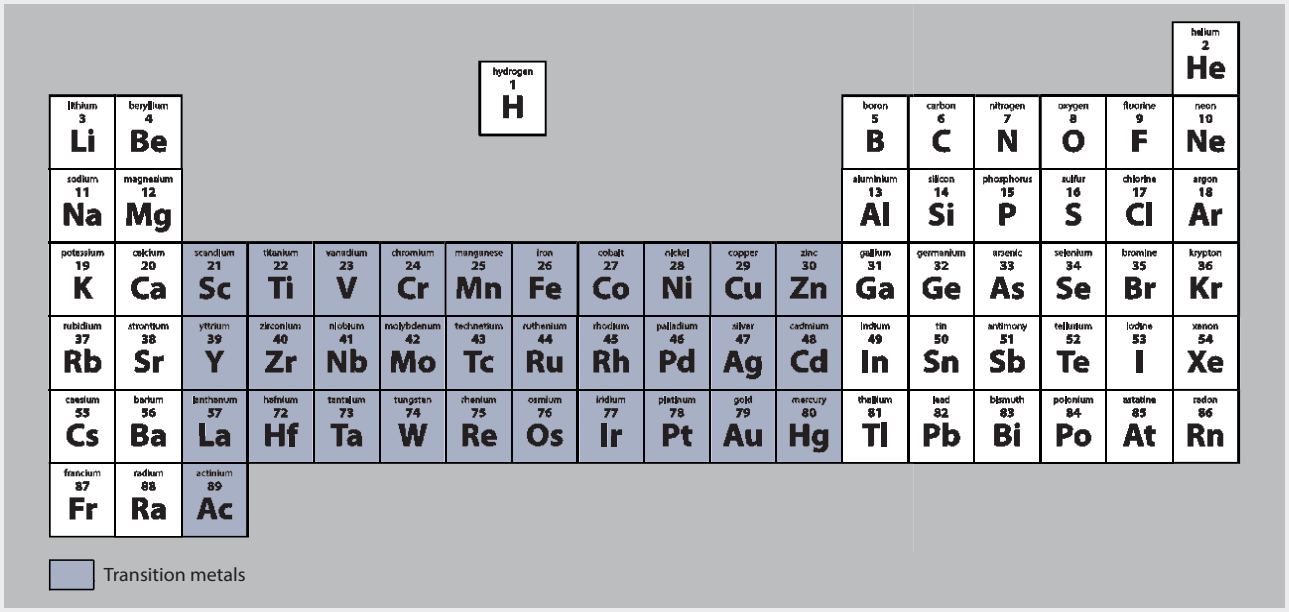
Interaction of electrons with visible light causes most selective absorption related gem colors.



Christopher Cruz/GIA

An electron's energy levels are like a ball bouncing on stairs. While the ball bounces easily down the stairs, it's harder for it to bounce up. To make the transition from lower to higher energy levels, electrons need to absorb energy. When they return from higher to lower levels, they lose energy. If the energy gained or lost happens to be in the visible light range, color can result.

The Periodic Table of Elements



Christopher Cruz/GIA

This simplified version of the periodic table arranges chemical elements in an orderly system of rows according to atomic number. Elements with similar atomic structure and similar chemical properties appear in vertical columns. The shaded area in the center indicates the transition elements, which interact with light to cause many of the colors in gems.

Scientists have an orderly way of classifying elements to clarify their properties and explain their capacity for combining with other elements. The so-called periodic table of elements was developed by Dmitri Mendeleev in 1869. It has been refined and expanded many times since then, as new elements were discovered or synthesized. As of 2017, it consisted of 118 elements.

Every element has its own atomic number, which is the number of protons in its nucleus. In the table, it usually appears in the upper left corner of the element's box. Each element is identified by its symbol—a single letter or set of letters. For example, aluminum's symbol is Al, oxygen's is O, and beryllium's is Be.

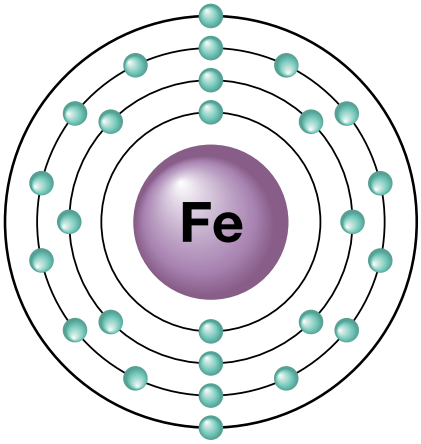
The periodic table is arranged in an orderly system of rows and columns. The horizontal rows, called periods, are arranged by atomic number, from lowest to highest and left to right. All the elements in each row have the same number of valence shells, and a new row starts each time a shell is added.

The vertical columns, called groups, consist of elements related by having the same number and arrangement of electrons in their outermost shells. This gives them a similar capacity for combining with other elements. One electron is added from group to group, left to right.

The group in the middle of the table has special relevance to gemologists because they cause many of the reactions with light that give rise to gem color. These are the transition elements, sometimes called transition metals. They're not part of a gem's basic chemistry but they can be present in the crystal structure as color-causing elements. When corundum's trace elements are iron and titanium, it's blue sapphire; chromium can make it a red ruby or pink sapphire. Trace amounts of chromium or vanadium give emerald its green color.

The kinds and relative quantities of atoms in a gem crystal can be expressed as a chemical formula. For example, the chemical formula for corundum is Al_2O_3. This means that pure crystals of corundum are composed of a precise ratio of aluminum (Al) and oxygen (O) atoms. To form an electrically neutral corundum crystal, the atoms have to combine in a ratio of two aluminum ions to every three oxygen ions. When only aluminum and oxygen are present, the corundum is absolutely pure and colorless.

The Iron Atom



I R O N

Atomic mass:
55.845

Atomic number:
26

Electron configuration:
2, 8, 14, 2

Christopher Cruz/GIA

Although atoms are the basic building blocks of matter, they contain still smaller particles—protons, neutrons, and electrons. Protons and neutrons are located in the nucleus, and electrons are in orbit around them. The iron atom provides a good example of this structure.

Iron provides an easy to understand example of an atom's structure and helps explain the numbers in the periodic table. Iron's symbol is Fe and 26 is its atomic number. Another number—56—is iron's atomic mass, which is approximately equivalent to the combined number of protons and neutrons in its nucleus.

Iron has four shells around its nucleus, all occupied by orbiting electrons. Its shells, from innermost to outermost, contain 2, 8, 14, and 2 electrons. Electrons in the outermost shell have the most energy, while those in the shells closer to the nucleus have progressively lower energy levels.

It's relatively easy for iron to give up the two electrons in its outermost shell. When that happens, it becomes an ion with two positive charges because the protons' positive charges are no longer balanced by the outermost two electrons. The iron atom can also gain a higher positive charge by losing more than two electrons.

You won't necessarily have to explain atomic structure or the periodic table of elements to your customers when you're selling colored stones to them, but it can help you understand the relationships among the elements that form the basic structure of the gems they love.

Transition Elements

Transition elements—Elements that can selectively absorb some wavelengths of visible light and produce color in gems.

As you learned in Assignment 3, trace elements are atoms in a gem that aren't part of its essential chemical composition. Certain trace elements are called *transition elements* or transition metals. They share many unique properties because of the way their electrons are arranged, but the most important aspect for gemologists is that their electrons absorb certain wavelengths of white light to produce color in gems.

When they absorb light, they also absorb the energy they need to move from the ground state to the excited state. When they scatter—or disperse—through the gem's structure in parts per million, scientists often refer to them as "dispersed ions" or "crystal defects."

Nicolas DelRe/GIA, courtesy A La Vieille Russie, New York City

Chromium causes fine green hues in many gems. It's responsible for the color of the vibrant green demantoid garnets that grace this Russian pin from the 1920s.

KEY CONCEPTS

Chromium causes the most desirable red and green gem colors.

Tino Hammid/GIA, courtesy Neil Lane Jewelry, Beverly Hills

Kevin Schumacher/GIA, courtesy Keiko Chung

Chromium can produce different colors in different gems, like the superb emeralds and rubies in these necklaces. In each gem, six oxygen atoms surround each chromium impurity, but slight differences in distance between the atoms are enough to produce their very different colors.

Colors Caused by Dispersed Ions

Dispersed ions cause many of the most popular gem colors. Gemologists consider chromium to be the cause of the finest, richest red and green gem colors. Tiny traces of chromium color red spinel, the best pyrope and demantoid garnet, and the finest, most cherished green jadeite.

Chromium is responsible for the color in both ruby and emerald. The chromium ion's valence is the same in both gems, and it's surrounded by the same arrangement of six oxygen atoms. However, the distance between each chromium atom and its oxygen neighbors is slightly different in each gem. That tiny difference is enough to color one gem red and the other green.

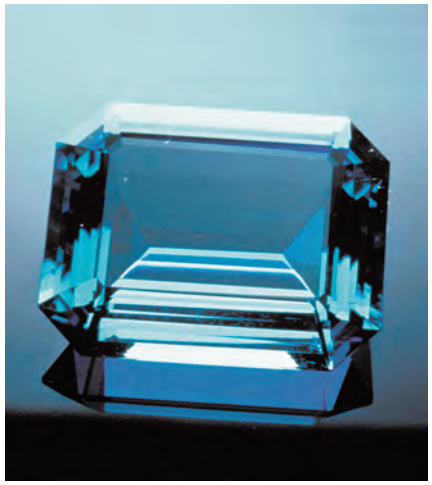
Vanadium also produces brilliant greens. It's just as important as chromium as the cause of color in some fine emeralds. Despite their name, most "chrome" tourmalines are actually colored by vanadium.

John Parrish , courtesy the Tsavorite Factory/Andre Assaf

Although dealers refer to some bright green gems from Africa as chrome tourmaline, their attractive hues are mostly due to traces of vanadium.

Bart Curren/ICA

Tino Hammid/GIA, courtesy Jonte Berlon



De'ev Dvir/ICA, courtesy Gemstar Ltd., Israel

Iron causes yellow, green, and blue colors in many gems, including yellow sapphire (left), peridot (center), and aquamarine (right).

Tino Hammid/GIA, courtesy Tim Roark

Adrian Pingstone

The transition element cobalt colors bright blue glass (above) and synthetic spinel (left), as well as some fine natural spinels.

KEY CONCEPTS

Iron causes a greater variety of gem colors than any other transition element.

Iron causes a greater variety of colors in gems than any other transition element. It can make gems green, but the color tends to be more muted than the green caused by chromium or vanadium. Besides peridot's green, iron produces almandine garnet's red, the blue of aquamarine, and yellow in sapphire and chrysoberyl. It also works together with titanium to produce blue in sapphire, blue spinel, kyanite, and possibly some tourmaline.

Cobalt causes the bright blues of synthetic spinel, some synthetic sapphire, and some manmade glass. It can also produce, along with iron, the strong blue of some fine, natural spinel.

Tino Hammid/GIA, courtesy Varujan Arslanyan

Tino Hammid/GIA, courtesy Pala International

Many gem colors result from more than one transition element. Most yellow sapphires get their color from iron. If they also contain chromium, their color might vary from pinkish orange to strong reddish orange (left). In the same way, demantoid garnet (right) might be yellowish green or greenish yellow, depending on the balance between iron and chromium.

Shane McClure/GIA, courtesy MCM Gems

Traces of copper caused this tourmaline's electric blue hue.

Tino Hammid/GIA, courtesy Jonte Berlon

The transition element manganese is responsible for the rich orange color of this 20.90-ct. malaya garnet from Tanzania.

Like cobalt, nickel colors some synthetic spinel and synthetic yellow sapphire, but it usually produces greens similar to the colors of peridot and tourmaline. It's also an important factor in the color of some natural chrysoprase.

Copper, long known as a cause of turquoise's blue, is also responsible for the fabulous "electric" blues and greens of certain tourmalines from Paraíba, Brazil. Before the discovery of this deposit, these intense colors had never before been seen in this gem. You'll learn more about tourmaline from Paraíba in Assignment 23.

Manganese causes reds and pinks in beryl, and yellow to orange colors in garnet.

Sometimes a gem's color is the result of more than one transition element. For example, the demantoid variety of andradite garnet might contain iron, which produces a yellow color, as well as chromium, which produces green. The combination gives most demantoid garnets their characteristic yellowish green color. In the same way, a combination of iron and chromium might produce a range of yellow to pinkish orange in sapphire, depending on the amount of each transition element present.

How Valence and Crystal Structure Affect Color

The outermost shell of an atom is called its valence shell. An atom's ability to combine with other atoms is determined by the energy level of the electrons in its valence shell. The farther the electrons are from the nucleus, the higher their energy level. This helps them attract high-energy electrons from other atoms.

The electrons in an atom's outermost shell tend to interact with incoming radiant energy and bond with other atoms' electrons. An atom's outermost shell has eight potential slots for electrons to fill. When all eight are occupied, the atom is in a stable state. Otherwise, the atom needs to gain this stable state by bonding with other atoms, thus losing, gaining, or sharing electrons.

Bart Curren/ICA

Jeffrey Scovil, courtesy Carolyn Manchester Collection

The same transition element can sometimes cause different color intensities in the same gem material. Both the red crystal (above) and the pale pink fashioned gem (left) are beryl. Each gets its color from traces of manganese. The difference in color strength is not caused by different concentrations of manganese, but by the different electrical charges of the manganese atoms in each gem.

For example, an aluminum ion has three fewer electrons than it has protons. This gives it a charge of 3+. If an ion has more electrons than protons, it has a negative charge. An oxygen ion has two more electrons than protons, so it has a charge of 2-. In scientific texts, you'll see the valence state of ions—the number of electrons above or below its neutral state—written in this form: Al^{3+}, Cr^{3+}, Fe^{2+}, O^{2-}, and so on.

The valence state of a transition element ion can have a major effect on the hue and intensity of the gem's color. For example, traces of manganese can substitute for other elements in beryl's crystal structure, causing both delicate pink and strong red colors. In morganite, the manganese atom is missing two outer electrons, so it has a valence state of 2+ (Mn^{2+}) and its color is a pale pink. In red beryl, the manganese atom is missing three outer electrons (Mn^{3+}) rather than two, so the color is a bright strawberry red. The color is stronger in red beryl because the 3+ valence state of manganese absorbs a different amount of energy from visible light.

Along with the type of transition element ion and its valence state, a gem's crystal structure is also important. Because each gem species has a different crystal structure, the same transition element can produce entirely different colors in different gems.

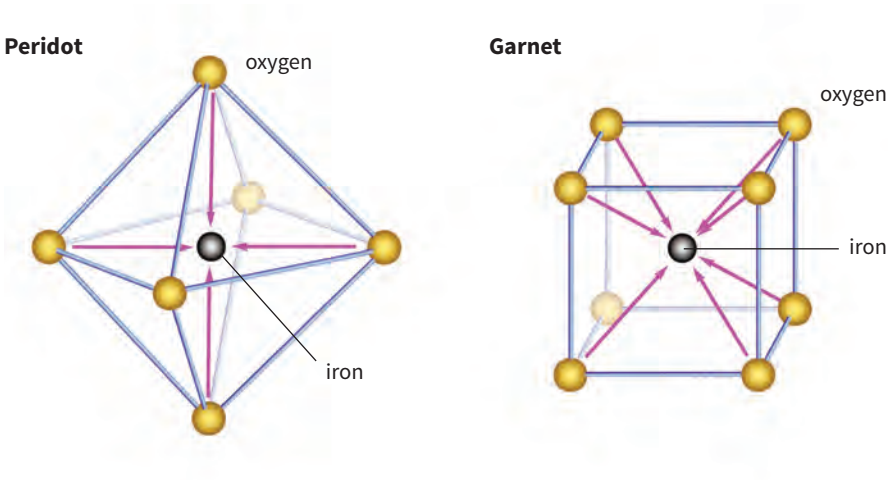
Both peridot and almandine garnet owe their colors to the same transition element: iron. In peridot's crystal structure, each iron atom is surrounded by six oxygen atoms. Garnet has eight oxygen atoms around each iron atom.

Because of these structural differences, the electrical forces acting on each iron atom are different enough to make almandine red and peridot green, even though both gems are colored by the same transition element.

KEY CONCEPTS

Valence differences can cause variations in color intensity in the same gem material.

Crystal structure variations result in the same transition element causing different colors in different gems.



Peter Johnston/GIA

Crystal structure can influence gem color. In peridot's crystal structure (left), six oxygen atoms surround each iron atom to produce a green gem. In almandine garnet's crystal structure (right), there are eight surrounding atoms, and the different electrical forces acting on the iron atom produce a red gem.

Shane McClure/GIA, courtesy David Humphrey, Mayer & Watt, Elise Misiorowski

The colors of allochromatic gems are caused by trace elements that aren't part of their essential chemistries. This collection from Sri Lanka includes corundum, spinel, and a yellowish green chrysoberyl.

Allochromatic and Idiochromatic Gems

Allochromatic—A gem colored by trace elements in its crystal structure.

Idiochromatic—A gem colored by an element that is an essential part of its chemical composition.

Some trace elements cause color because they selectively absorb the light that enters a gem. Many gems—including corundum—are colorless when pure, and only show color when certain trace elements are present. These gems are known as *allochromatic*, which literally means "other colored."

In ruby, for example, small amounts of chromium substitute for aluminum in the gem's crystal structure to give the gem its red color. The amount of chromium in the corundum's structure determines the red's intensity. If there's only a tiny amount of chromium, the result is a delicate pink sapphire. If the chromium content is higher, the gem's color might be a strong red.

In some other gems, the color-causing elements aren't present as trace elements, but are part of the gem's basic chemistry. Gemologists describe these gems as *idiochromatic*, which literally means "self-colored."

Tino Hammid/GIA, courtesy Gordon Bleck

Although each of these gems is a different color, their crystal shapes tell you they're all sapphire. Each crystal has the same arrangement of aluminum and oxygen atoms. Their different colors are caused by traces of other elements such as chromium, iron, and titanium.

Alan Jobbins

Generally, the more chromium a corundum contains, the stronger its color. The pale pink stone (second from right) contains 0.03 percent chromium, while the bright red one (second from left) has a chromium content of 0.10 percent. The darkest stone contains 1.00 percent chromium. These gems are all flame-fusion synthetics.

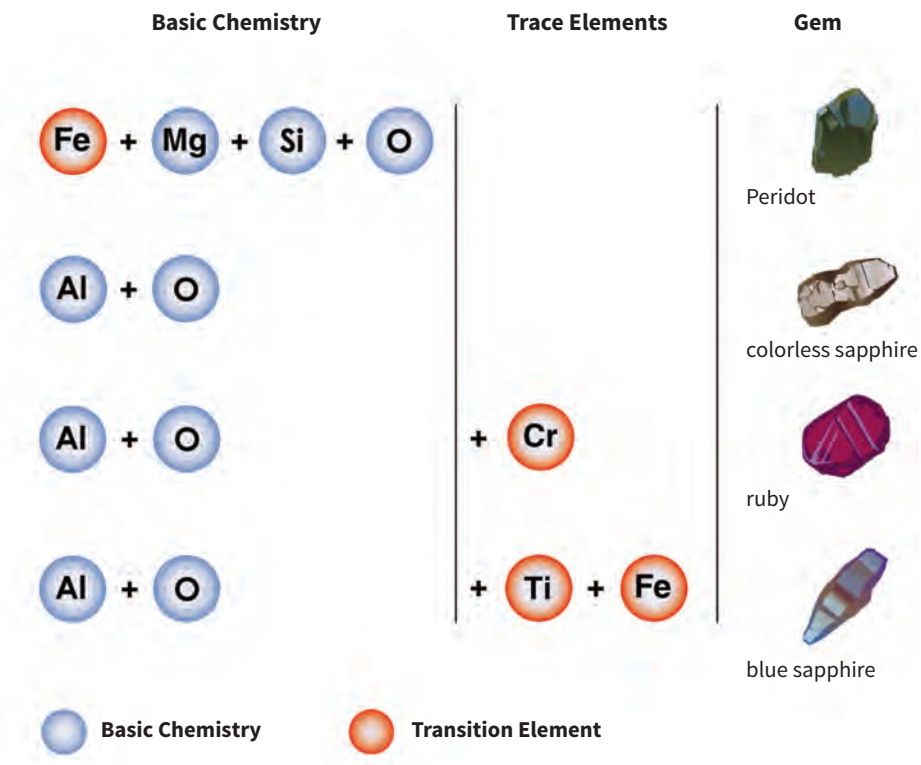
Shane McClure/GIA

The same element might produce entirely different colors in different gem species. The crystal structure of each of these gems interacts differently with the same element—iron—making the peridot green and the almandine garnet red.

Almandine garnet is an example. Its characteristic purplish red color is caused by iron. But the iron doesn't just substitute for another element in the garnet's crystal structure. It's part of the gem's own essential chemistry.

Peridot is another idiochromatic gem. Like almandine garnet, its color is caused by the presence of iron, but as you'll learn, its atomic structure is different. As a result, different forces act on the iron atom to produce green instead of red.

The color range of idiochromatic gems tends to be much more limited than the color range for allochromatic gems. This is because, with idiochromatic gems, the elements that cause color are part of their basic chemistry, so they're not subject to much variation. Compare peridot's yellowish green color with corundum's rich variety of yellows, oranges, reds, pinks, greens, and blues. Peridot's color is due to iron alone, but corundum's palette of colors is caused by various combinations of chromium, iron, titanium, and vanadium.



Peter Johnston/GIA

In some gems—like peridot—the transition element that causes color is part of the gem's basic chemistry and crystal structure. In others—like corundum—the transition elements aren't part of the gem's basic chemistry or crystal structure, but occur as impurities in the crystal.

Charge Transfer

You've learned how the electrons in transition elements selectively absorb some of the wavelengths of visible light to produce color. The electrons present in trace amounts of chromium in ruby's crystal lattice produce that gem's rich red color. Electrons absorb light to produce sapphire's rich blues too, but there's a slightly different mechanism at work.

In ruby, the electrons stay with the chromium ion, but in sapphire and many other gems, they can move between the transition elements and their neighboring ions. In fact, they're able to jump from one ion to another and back again, absorbing wavelengths of light as they move. Scientists call this movement of electrons between ions *charge transfer*.

Colors caused by charge transfer are more intense than those caused by dispersed ions. Compared to energy transitions within dispersed ions, charge-transfer transitions occur a lot more often and can be up to a thousand times stronger. The intensity of colors caused by both mechanisms also depends on the concentration of the ions involved.

Charge transfer gives many yellow gems their color. Golden beryl's deep yellow results from light absorption that occurs when electrons move back and forth between neighboring oxygen and iron ions. This produces a range of yellow to brown colors. The colors caused by oxygen-to-iron charge transfer are relatively independent of the gem material. It would produce a similar color even if the gem were corundum instead of beryl.

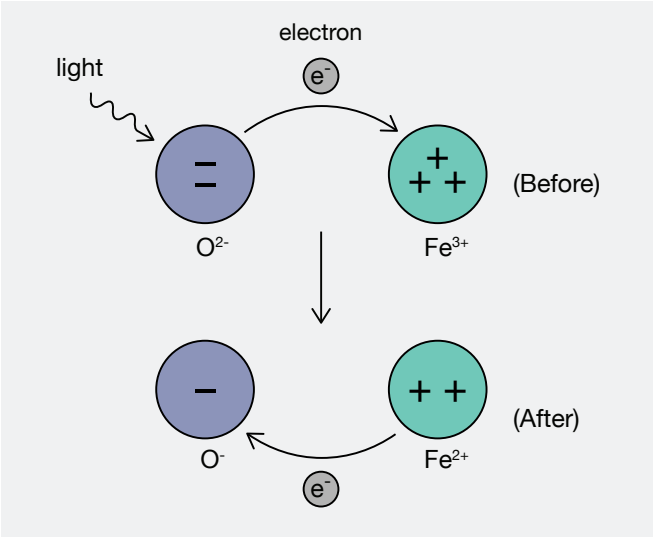
In some gems, especially aquamarine and blue sapphire, charge transfer takes place between two transition elements with different valences. Gemologists call this process *intervalence charge transfer*. Iron is a good example, because it can have either 2+ or 3+ valences.

KEY CONCEPTS

Colors produced by charge transfer are much stronger than colors caused by dispersed ions.

Charge transfer—The movement of electrons back and forth between ions, causing the selective absorption of light.

Intervalence charge transfer—A process where two transition elements with different valences exchange electrons to selectively absorb light.

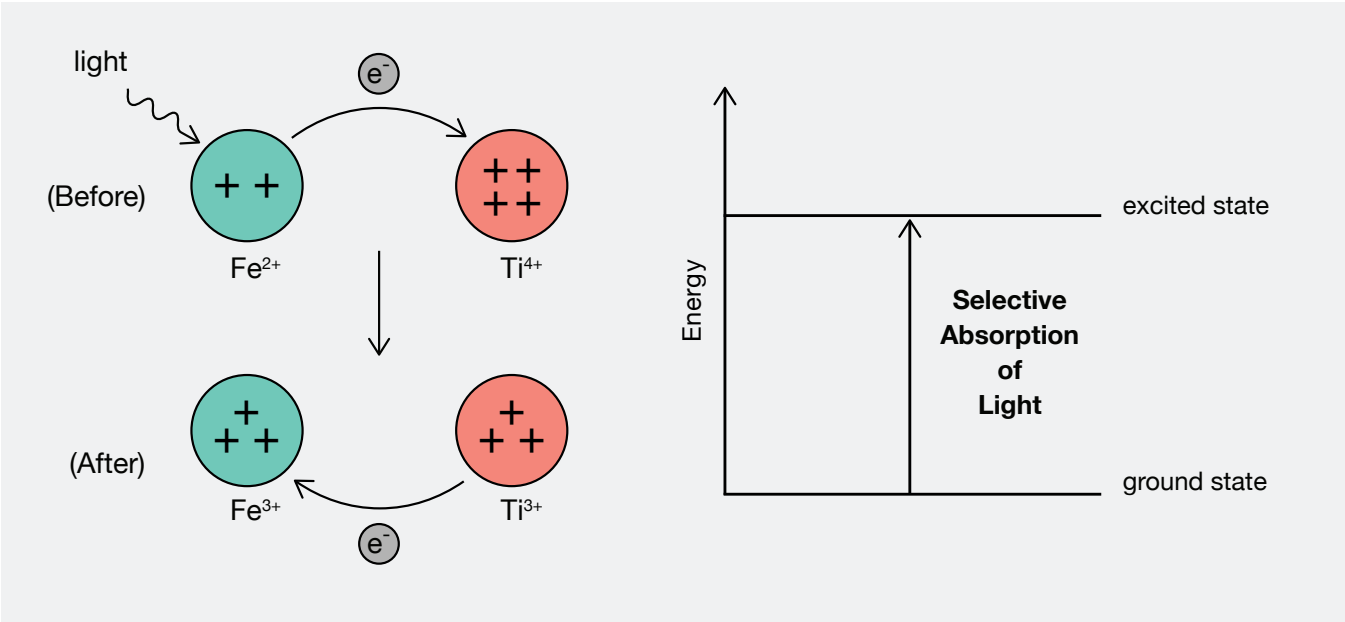


Christopher Cruz/GIA

Golden beryl's spectacular yellow color is due to a charge transfer between negatively charged oxygen ions and positively charged iron ions. As the electrons move between ions, they selectively absorb visible light.

Robert Weldon/GIA

Charge transfer between oxygen and iron produces yellow to brown colors in many gems, including this 18.60-ct. golden beryl.



Christopher Cruz/GIA

In a blue sapphire crystal, trace amounts of iron (Fe^{2+}) and titanium (Ti^{4+}) substitute for aluminum (Al^{3+}) in the crystal structure. Visible light supplies enough energy for an electron to make a transition between each iron-titanium pair. The energy from visible light raises the electron from its ground state to its excited state, and it selectively absorbs visible light to generate the gem's attractive blue color.

Tino Hammid/GIA, courtesy Benjamin Zucker

Intervalence charge transfer colors many gems blue. It's responsible for the stunning color of this fine Kashmir sapphire.

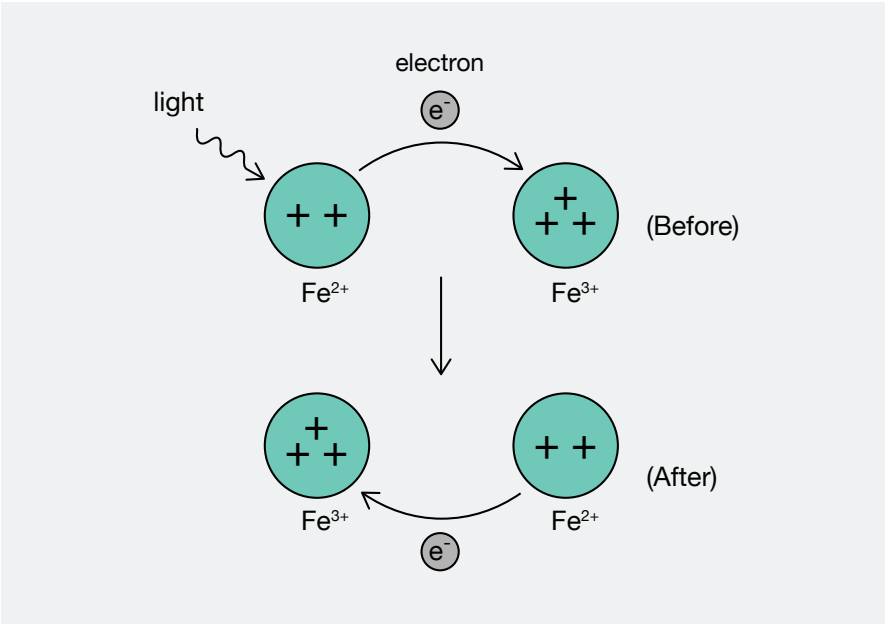
Blue sapphire is the gem world's best example of intervalence charge transfer. Pure corundum is colorless, but when trace amounts of iron and titanium substitute for aluminum in its crystal structure, charge transfer takes place between these two elements. An electron absorbs some of the energy from visible light to fuel its jump from the iron ion to the titanium ion. This produces sapphire's rich blue color. The electron's movement temporarily changes the valences of both ions, but the original valences are restored when it moves back.

Both charge transfer processes work together to produce aquamarine's color. When visible light enters an aquamarine crystal, an oxygen-to-iron charge transfer absorbs its violet components and produces yellow. At the same time, an iron-to-iron intervalence charge transfer absorbs red light and produces blue. Together, the two processes produce the gem's characteristic blue-green color. The balance between the two processes determines whether the gem's color is more greenish or more bluish.

Gem-treatment professionals use heat treatment to produce bluer, more marketable aquamarine by changing the valence state of the gem's iron impurities. The color depends on the relative strength of each type of charge transfer, so treaters only have to alter the balance between them. If the yellowish oxygen-to-iron charge transfer dominates, the gem's color is greener. If the iron-to-iron charge transfer is stronger, the gem is bluer. Treaters remove the undesirable greenish color by changing the valence state of some of the iron impurities from Fe^{3+} to Fe^{2+}. Heating adds electrons to the iron impurities so the bluer iron-to-iron charge transfer dominates over the yellowish oxygen-to-iron process.

KEY CONCEPTS

Treatment can alter or initiate some color-causing charge transfer reactions.



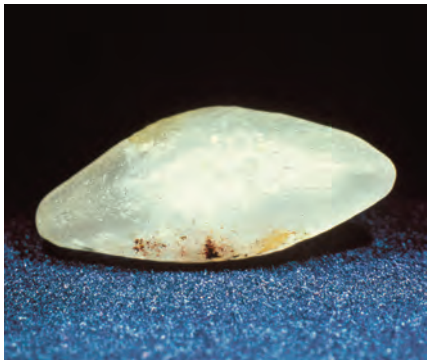
Christopher Cruz/GIA

The intervalence charge transfer that causes aquamarine's blue color happens when electrons move between pairs of iron ions with different valence states (Fe^{2+} and Fe^{3+}) and selectively absorb light.

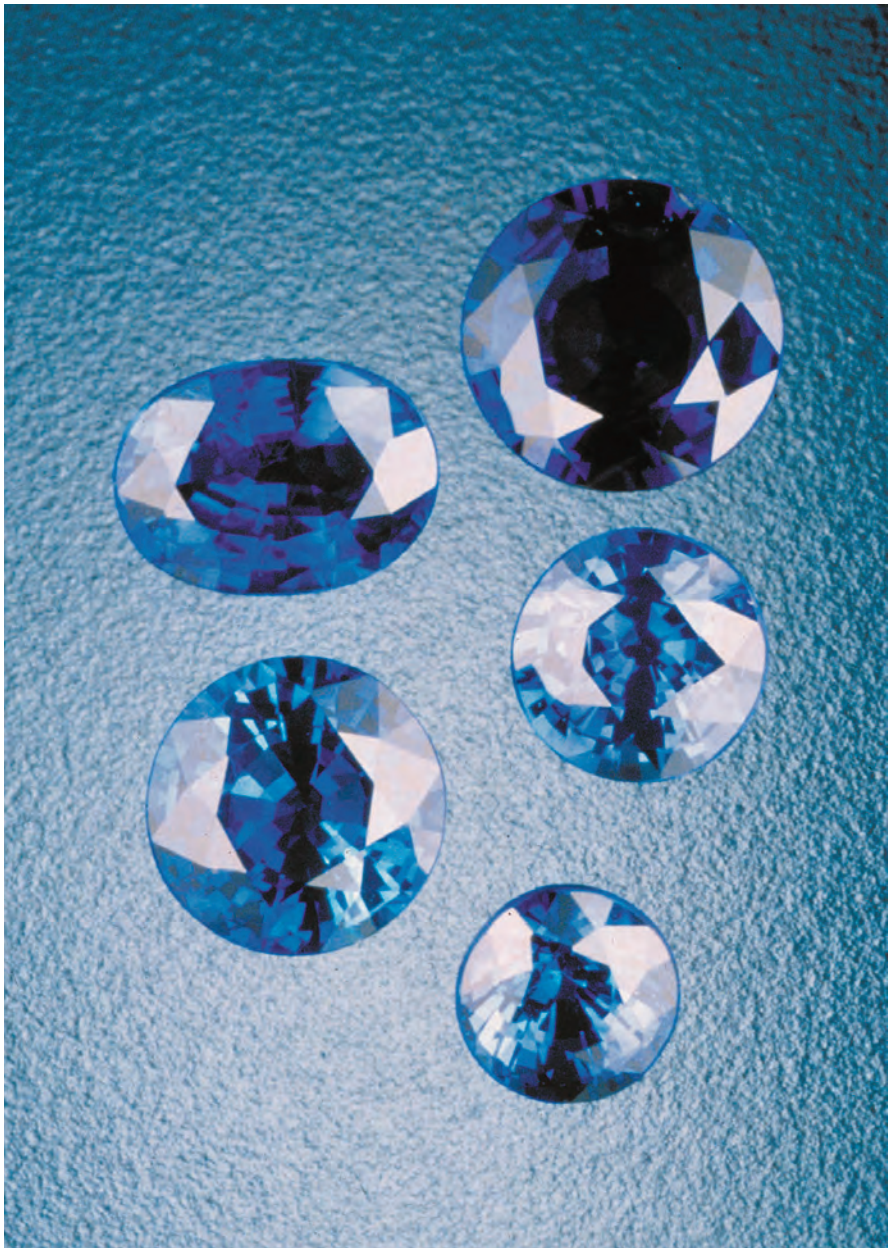
Jeffrey Scovil, courtesy Gene Meieran Collection

Robert Weldon/JCK Magazine

Untreated aquamarine's color is normally blue-green (left). Careful heat treatment can remove the yellowish component and produce a much more marketable blue color (right).



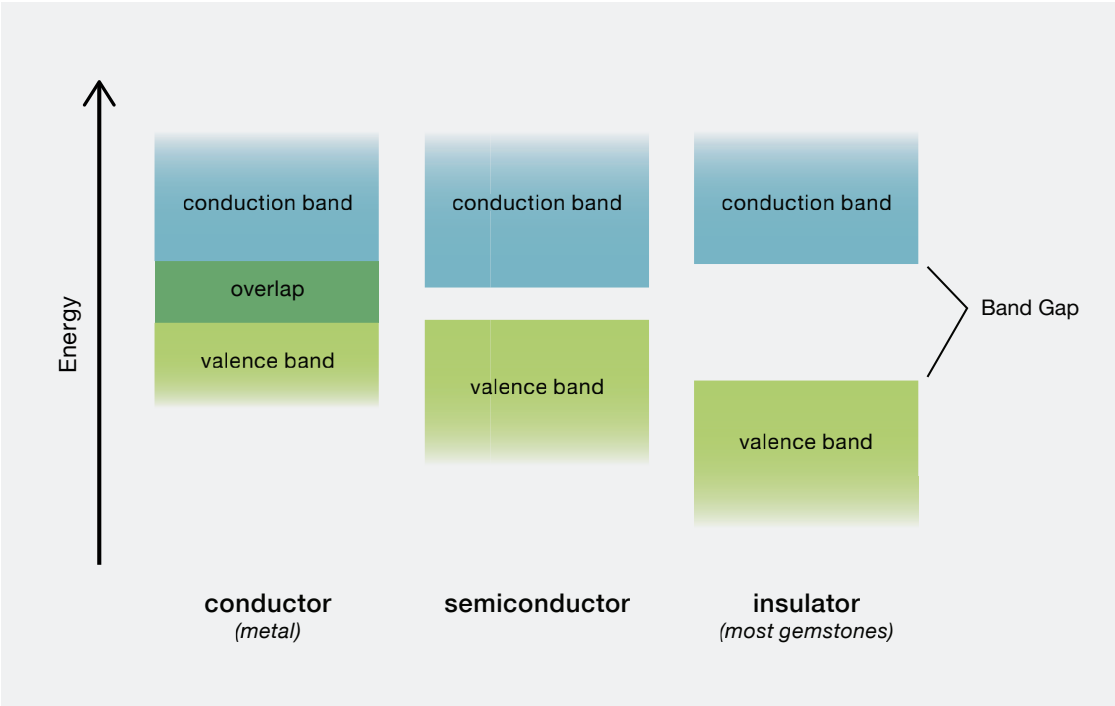
Tino Hammid/GIA



Tino Hammid/GIA, courtesy Kenneth Kin Ming Siu and Joao Jose Ip Iau Tchun

The milky corundum crystal (left) looks unpromising, but traces of titanium are trapped in mineral inclusions within it. Careful heating can unlock the titanium, which can pair with iron to produce marketable blue gems like these treated Madagascar sapphires (above).

In many blue sapphires, the intervalence charge transfer takes place between iron and titanium. When titanium ions are locked into mineral inclusions within the sapphire, the gem appears near-colorless or milky. Treatment can release them into the crystal by heating and then cooling the gem under the right conditions. This releases the titanium impurities into the crystal, where they pair with iron to convert unappealing milky corundum into highly marketable blue sapphire.



Christopher Cruz/GIA

The band structure of a solid material includes a lower-energy valence band and a higher-energy conduction band. The space between the two is called the band gap. In metals, the valence and conduction bands overlap. In gems they do not, and the energy from visible light is not enough to allow electrons to move directly from the valence band to the conduction band. As a result, most gems are colorless when pure.

Band Theory

Band theory visualizes the movement of an atom's outermost electrons from their lower-energy valence bands toward their higher-energy conduction bands. Scientists use band theory to understand some of the basic properties of materials, including why some substances—metals like copper—conduct electricity and other materials—gems like corundum—do not.

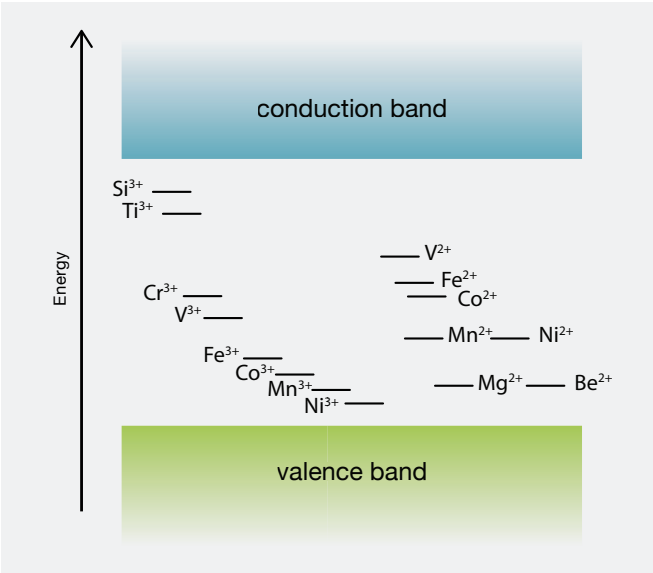
In many materials, a constant energy difference—called the band gap—separates the valence band from the conduction band. In general, the narrower the band gap, the easier it is for electrons to cross it. In a conducting material like copper, the valence and conduction bands overlap, so electrons can move easily between them.

In most gems, the valence band's energy level is much lower than that of the conduction band. The band gap in those gems is so large that visible light doesn't provide enough energy for electrons to move directly from one to the other. This explains why many gem materials are colorless when pure.

For electrons to make the transition, they need to conquer this gap. If the gem contains traces of impurities like transition elements, the impurities can add new energy levels that help electrons move across the band gap and absorb some visible light wavelengths.

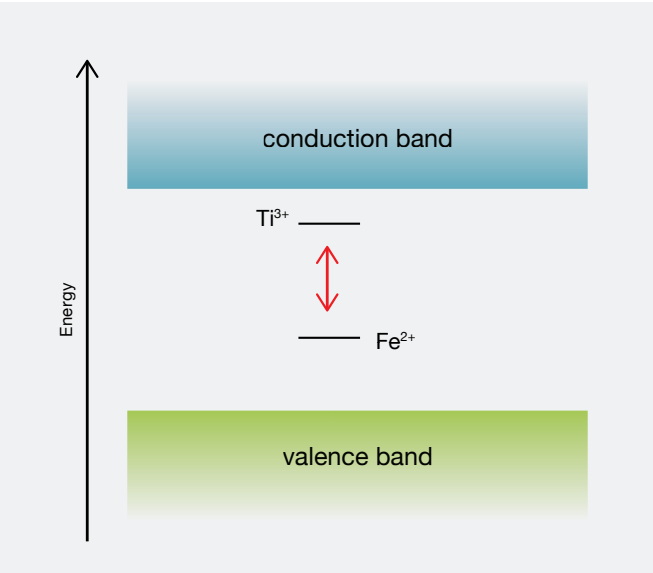
KEY CONCEPTS

The presence of transition elements adds new energy levels within a gem's band gap, helping electrons absorb some visible light wavelengths.



Christopher Cruz/GIA

When trace elements add energy "steps" within corundum's band gap, it lowers the energy required for an electron to make a transition and selectively absorb visible light to produce color. Knowledgeable gem treaters can even add impurities—like beryllium—to enhance the color of treated stones.



Christopher Cruz/GIA

The charge transfer reaction that colors blue sapphire takes place within corundum's band gap. The presence of titanium and iron impurities allows electrons to make transitions within the band gap and selectively absorb visible light.

Corundum is a good example. Pure corundum is colorless because it has a large band gap. However, traces of transition elements like chromium, iron, and titanium cause color through selective absorption. Color is generated by transitions of electrons within, or between, those elements. Their presence creates more energy levels within corundum's band gap, lowering the energy required for electrons to move and produce color. The newly added energy levels act as steps between the valence and conduction bands, making the electron's transition easier.

Since the gaps are smaller between the steps and the bands, some wavelengths of visible light can provide enough energy for transitions to occur. When an electron absorbs some visible light to make a transition within the band gap, the unabsorbed wavelengths produce the gem's color.

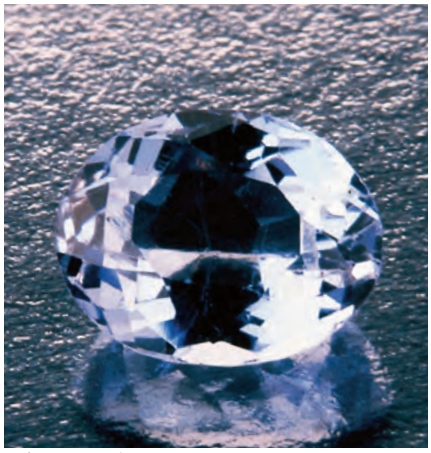
Color Centers

You don't have to imagine a vibrant sapphire-like blue beryl. Such a stone does exist, and it's known as Maxixe (mah-SHEE-she) beryl. Unfortunately, its lovely color fades in sunlight, making it impractical for gem use. Maxixe beryl's color is caused by a small light-absorbing defect trapped in its crystal structure. The defect is called a *color center*.

Color center—A small defect in the crystal structure of a material that can absorb light and give rise to a color.

A color center can be a missing or extra atom that distorts the surrounding crystal structure. With Maxixe beryl, the powerful absorptions that contribute to the blue color are caused by small defects in its crystal structure that result from irradiation of a nitrogen-containing impurity (NO^3).

Maha Tannous/GIA



Maha Tannous/GIA

Some gem color is unstable when exposed to visible light. This 3.34-ct. Maxixe beryl (left) faded dramatically after eight hours' exposure to sunlight (right).

Jeffrey Scovil

The color of irradiated blue topaz is permanent and doesn't fade with exposure to light.

Color centers can be caused by natural or manmade conditions. Maxixe beryl is exposed to naturally occurring radiation in the earth. The colors of many other gems, including most blue topaz and some pink tourmaline, are caused by *irradiation*—exposure to radiation in a lab.

Irradiation—A treatment in which a gem is exposed to radiation to change or improve its color.

Radiation can affect a gem's color in two ways. It can change the valence state of an ion or it can interact with the gem's crystal structure. Usually, high-energy radiation knocks an electron from its orbit, resulting in absorption that produces color. This is what happens in Maxixe beryl.

Irradiation is the most common way to generate color centers in gems, while heating usually removes them along with the colors they produce. Irradiation exposes gems to very high-energy sources—typically higher than the range of visible light. This causes irregularities in the crystal structure by moving atoms or electrons from their normal locations to form color centers.

Mike Havstad/GIA

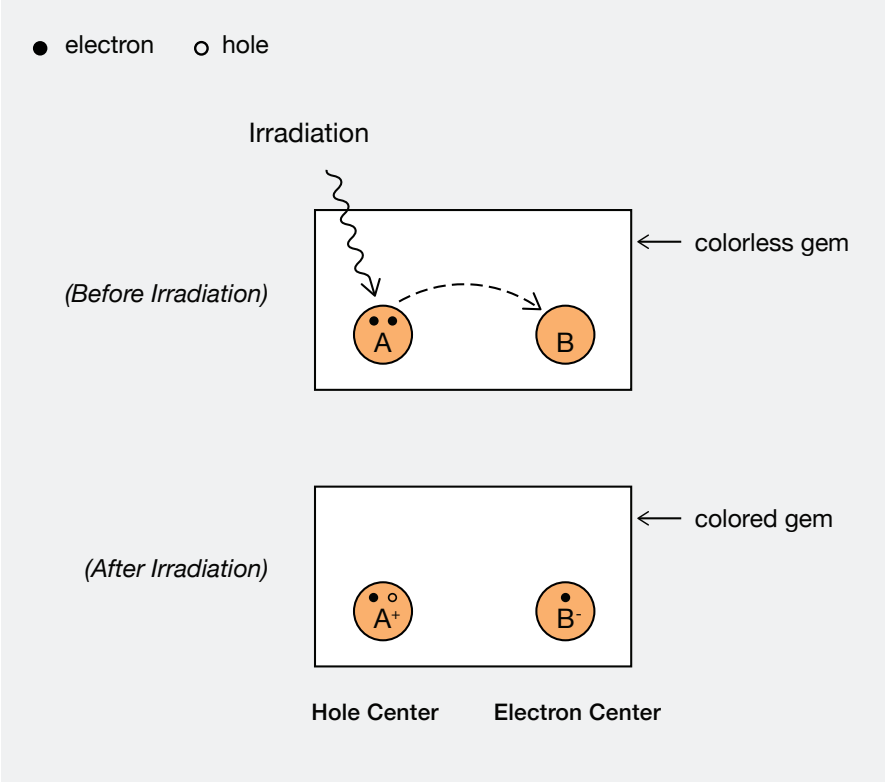
Mike Havstad/GIA

Treaters can irradiate light yellow sapphire (left) to a strong orange color (right), but the results aren't permanent. The gems soon fade back to their original color with exposure to heat or sunlight.

In most cases, irradiation dislocates electrons rather than whole atoms. As you learned earlier, when ions bond together to form crystals, they produce electrically neutral structures. Once an ion is removed or added, other charged particles—such as electrons—balance the charge to keep the crystal electrically neutral.

When an electron is evicted from an atom in the crystal structure, it leaves what's called a hole center, also sometimes known as a trapped hole. And when a particle or a vacancy in the crystal structure attracts an electron, it forms a so-called electron center. These two types of color centers often exist together, and they can generate colors alone or in combination.

Hole centers cause the brown of smoky quartz and the purple color of amethyst in a two-step process that can happen in nature or in a lab. To take on a smoky color, the quartz crystal must contain trace amounts of aluminum. The aluminum substitutes for the silicon atoms that are part of the essential crystal structure of quartz. Due to the different charge between the aluminum and silicon ions, the crystal draws in some hydrogen and sodium ions to remain electrically neutral. After that happens, the crystal is still colorless unless natural or manmade radiation is applied.



Christopher Cruz/GIA

When irradiation evicts an electron from an atom (A), it leaves a space called a hole center. This gives the atom an additional positive charge. If a nearby atom (B) takes in the evicted electron, it gains an additional negative charge, resulting in a so-called electron center. Hole and electron centers often occur together. Although either one might be responsible for gem color, they can also work together.

The radiation removes an electron from an oxygen ion that's near an aluminum ion. This creates a hole center that causes the brownish and grayish colors of smoky quartz. The hole center and the color can be removed by heating the gem a few hundred degrees.

A similar mechanism causes amethyst's color. Trace amounts of iron replace some of the silicon, producing citrine's yellow color. Then, exposure to natural or manmade radiation removes electrons from the iron impurities, changing their valence states from 3+ to 4+ (Fe^{3+} to Fe^{4+}). As long as the gem contains traces of iron, an oxygen-to-iron charge transfer (O^{2-} to Fe^{4+}) takes place, absorbing yellow, green, and orange light to give amethyst its characteristic purple color.

The yellow of some attractive natural sapphires is caused by traces of magnesium substituting for aluminum in the crystal lattice. Magnesium has a valence state of 2+ (Mg^{2+}) and the aluminum it replaces has a valence state of 3+ (Al^{3+}), so there is one less positive charge than if the aluminum ion were present in that site. In order to remain electrically neutral and balance the charge, an adjacent oxygen ion has to lose an electron. This creates a hole center, which causes an adjacent oxygen ion to become O^{-} rather than O^{2-}. If there are also traces of iron (Fe^{3+}) in the sapphire, there's potential for a strong yellow color.

KEY CONCEPTS

Irradiation produces color in gems by creating color centers.

Color centers allow selective absorption to take place by lowering the energy required for electrons to make transitions in a gem's band gap.

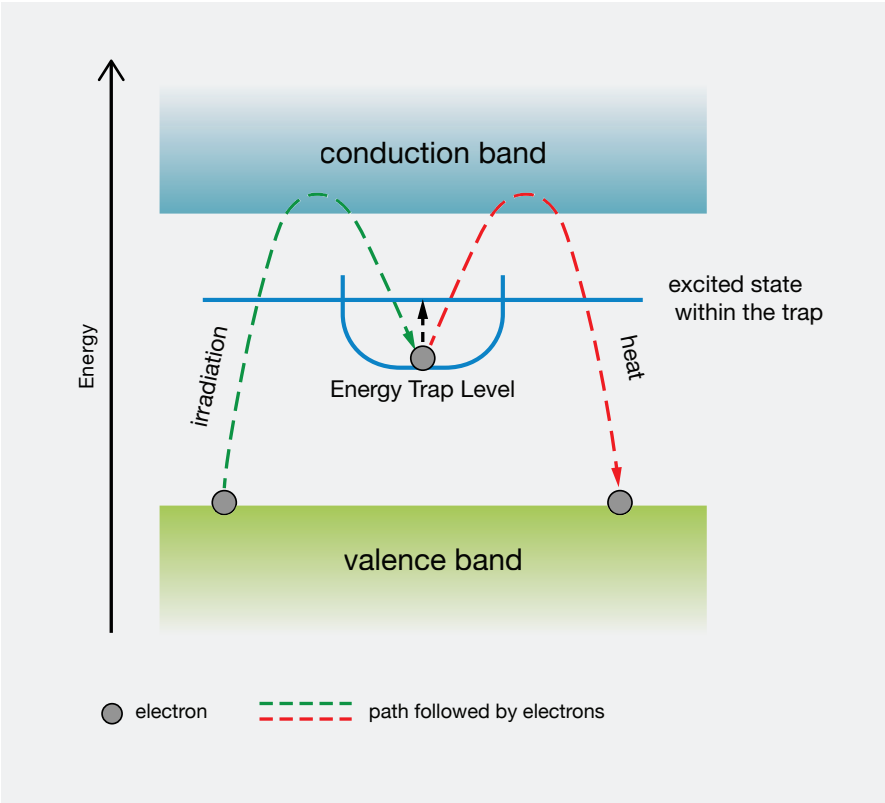
How Color Centers Work Within Band Gaps

Band theory explains how color centers form and create color, and why irradiation—or even in some cases exposure to visible light—can remove them and the colors they produce. Most gems have large energy gaps in their band structures. When visible light doesn't provide enough energy to allow electrons to jump over the gaps, these stones are colorless.

If you apply higher levels of energy—irradiation—to a colorless gem, it might excite electrons enough to let them jump from the valence band to the conduction band. Once the energy is removed, the electrons simply fall back into the valence band and release the energy gained from irradiation.

If the color centers are produced by irradiation, something else happens. The presence of color centers creates what scientists call energy traps within a gem's band gap. The color centers trap the electrons that were excited by irradiation within the gap, rather than letting them return to the valence band. With the stimulus of visible light, the electron jumps from the bottom of the trap to a higher-energy excited state within the trap. This makes the transition much easier than conquering the entire band gap, so there's enough energy to excite the trapped electrons to a higher-energy state and absorb some wavelengths of visible light to produce the gem's color.

The energy supplied by visible light allows an electron to move to a higher-energy state within the trap, but not enough for it to escape back to the valence band. For this to happen, more energy—typically introduced through heat treatment—can be applied to the gem to allow the electrons to escape the trap, destroy the color center, and remove the gem's color.



Christopher Cruz/GIA

Color centers produce so-called energy traps within many gems' band gaps. High-energy irradiation excites the electron from the valence band to the conduction band, but instead of falling back to its original position, it becomes trapped. Visible light provides enough energy to allow the electron to make transitions within the trap—and selectively absorb light—but not to escape. Heating can provide enough energy to destroy the color center by allowing the electron to escape the trap and return to the valence band.

KEY CONCEPTS

Heat treatment removes unwanted colors by destroying the color centers that cause them.

The electron then jumps back through the conduction band to the valence band. Many gem treaters understand this process, so they heat gems to destroy color centers and remove unwanted colors.

Only a very small amount of energy is required to destroy the color centers in some gems such as kunzite. The trap in kunzite's band structure is extremely close to the conduction band, so even visible light can supply enough energy for the electron to escape the trap. This causes kunzite to fade over time.

Other gems also have unstable color centers that cause them to fade when exposed to heat or light. Colorless sapphire can be irradiated to an intense yellow. However, the treatment only displaces electrons a short distance from their original positions, and they're only weakly held there. As a result, it doesn't take much to draw them back in place. The strong yellow color of irradiated yellow sapphire vanishes with gentle heating or exposure to sunlight. If the displaced electrons are held tightly in their new locations— as in treated blue topaz and irradiated pink tourmaline— the resulting color is more stable.

Color-causing mechanism	Explanation:
Transition element	Gem color is produced when electrons of individual transition element ions selectively absorb some wavelengths of visible light.
Charge transfer	Visible light supplies the energy for electrons to transition between ions. As they make these transitions, electrons selectively absorb some wavelengths of visible light to produce a gem's color.
Band theory	Impurities and defects provide additional energy levels in some gems' band gaps. Electrons can more easily make transitions between these energy levels within the band gap by selectively absorbing visible light and producing color.
Color center	Defects in gem crystals produce energy traps within band gaps. There's enough energy from visible light for electrons within the traps to make transitions and selectively absorb visible light to produce color.

Fluorescence and Phosphorescence

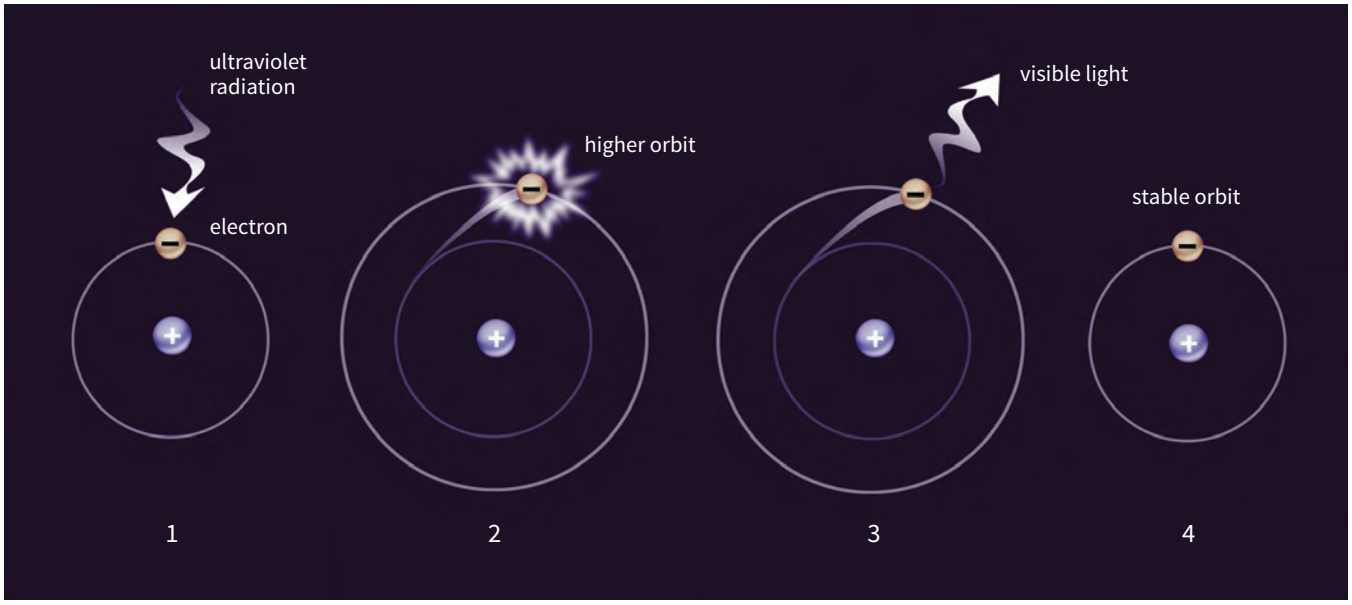
You've learned that the electrons in transition elements absorb certain wavelengths of light and that when electrons absorb light, they also absorb energy. To return to their normal stable state, they have to release that energy. Most of the time, it passes into the crystal as heat. But sometimes, some of the energy is converted into visible light and emitted by the gem. This is called *fluorescence*. The light emitted by the gem usually has lower energy than the light it absorbs. For example, if the gem is irradiated with ultraviolet light, the light it emits usually has longer wavelengths and falls into the range of visible light.

Fluorescence—Emission of visible light by a material when it's stimulated by ultraviolet or X-ray radiation.

Fluorescence makes some rubies resemble hot coals by creating an extra red glow over and above their usual ruby-red color. The reaction can be apparent in daylight, which contains some ultraviolet (UV) light. It's even more striking if you expose the stone to a source of UV radiation or X-rays.

This effect can be useful for gem identification. UV radiation is invisible, but when it interacts with some gems, it can cause them to emit visible light, or luminesce. X-rays can also cause luminescence, but gemologists normally use UV radiation for gem identification.

Ruby's fluorescence is caused by the presence of the transition element chromium, which is also responsible for the gem's color. The red fluorescence can enhance the gem's red color and make it seem more vibrant.



Peter Johnston/GIA

Fluorescence happens when a UV stimulus (1) provides the energy that allows an electron to rise from a stable orbit to a higher one around the atom's nucleus (2). The electron completes the cycle by releasing the energy as visible light (3) and returning to its normal stable orbit (4). If the emitted fluorescent light is in the visible light range—like the red glow of ruby—your eyes can detect it.

Not all rubies display fluorescence. That's because some elements can interfere with chromium's effect. Iron, which is frequently present in ruby crystals, inhibits fluorescence. The energy that's transferred from the chromium to the iron is released as tiny amounts of heat instead of visible light.

Fluorescence lasts as long as the gem is being stimulated by the radiation. With *phosphorescence*, the gem continues to fluoresce after the radiation source is removed. Fluorescence is much more common than phosphorescence.

So far, you've seen how selective absorption colors gems. Next, you'll learn about some other properties that influence the interaction between gems and light.

Properties Related to Light Interaction

- How does crystal structure influence the way a gem interacts with light?
- What causes double refraction?
- What causes pleochroism?

Some gem crystals, like spinel and garnet, are usually very symmetrical. Others, like tourmaline and ruby, are longer or shorter in one dimension than another. In Assignment 3, you saw that a crystal's external shape gives clues to the symmetry of its atomic structure. Even a well-formed tourmaline crystal is less symmetrical than a well-formed spinel crystal. And a rough spinel crystal's eight equal triangular sides indicate the inner order of its atoms.

Phosphorescence—Continued emission of visible light after UV or X-ray stimulation stops.

Refraction—Change in speed and possible change in direction of light as it travels from one material to another.

Doubling—The appearance of double images of a gemstone's facet junctions on the side opposite the viewer.

Robert Weldon/GIA

Jeffrey Scovil

A spinel crystal's highly symmetrical octahedral shape (above) reflects the symmetry of its internal structure. Tourmaline's long, columnar crystal shape (right) is less symmetrical, reflecting directional differences in its atomic structure.

Gems handle light in different ways because their internal symmetry and crystal structure are different. Their structural differences produce readily visible and measurable effects.

Refraction

As light enters a crystal, it slows down. It also might change direction. This is because the crystal's atoms are more densely packed than the atoms in the air around it. Scientists call this change in speed and direction of light *refraction*. Refraction occurs when light travels from one material to another.

The instrument most often used to help identify gems is the refractometer. It measures refractive index (RI) which influences how much light slows down or bends when it enters the gemstone. You'll learn more about the refractometer in the GIA *Gem Identification* course.

Some gems bend and slow light more than others. Diamond and andradite garnet are gems with high RIs. They bend and slow light much more than low-RI gems like quartz and opal.

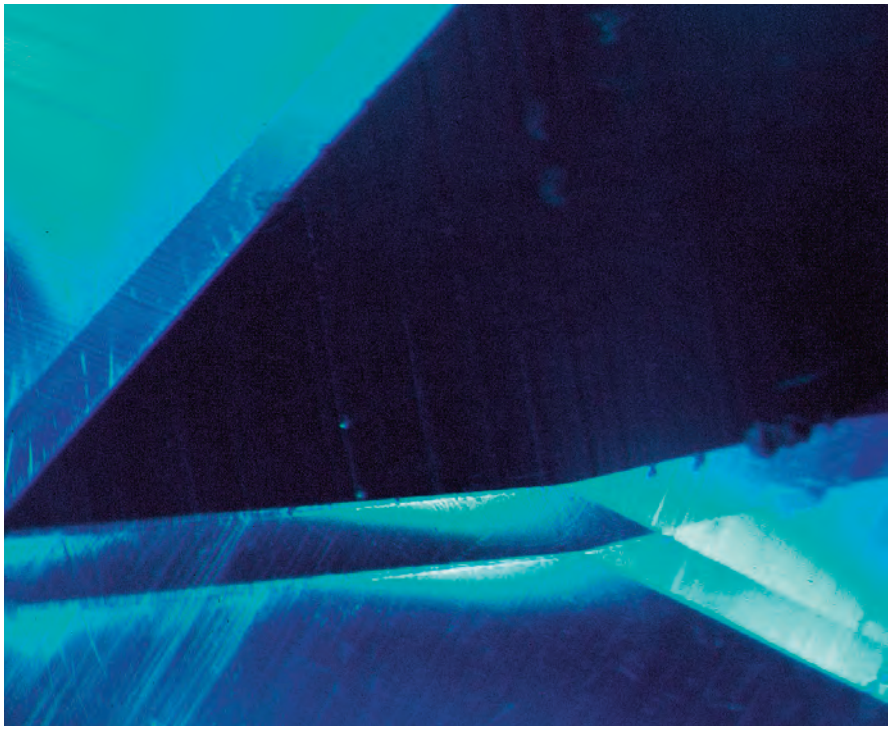
Some gems do more than just slow light down and change its direction: they split light into two separate rays. If you look closely into the crown of a faceted zircon, you'll often see a double image of the gem's pavilion facets. You can sometimes see the same effect in peridot. It's called *doubling*.

Ann Bilinski

When light enters a gem crystal, it slows down and often changes direction. A refractometer helps gemologists observe the results of this action. The amount of slowing is different for every gem, which is why this instrument is useful for identifying many gemstones.

Mike Havstad/GIA

Calcite's double refraction is even more extreme than zircon's. If you place a transparent calcite crystal on a printed page, you'll see a double image of the text.



A gem's atomic structure sometimes splits incoming light into two rays. This zircon's facets appear doubled because of split light rays.

Double refraction—When a gem's crystal structure splits light into two rays that each travel at a slightly different speed and direction.

Single refraction—When a gem's crystal structure doesn't change incoming light other than by refraction and absorption.

Optic axis—Direction of single refraction in a doubly refractive gem.

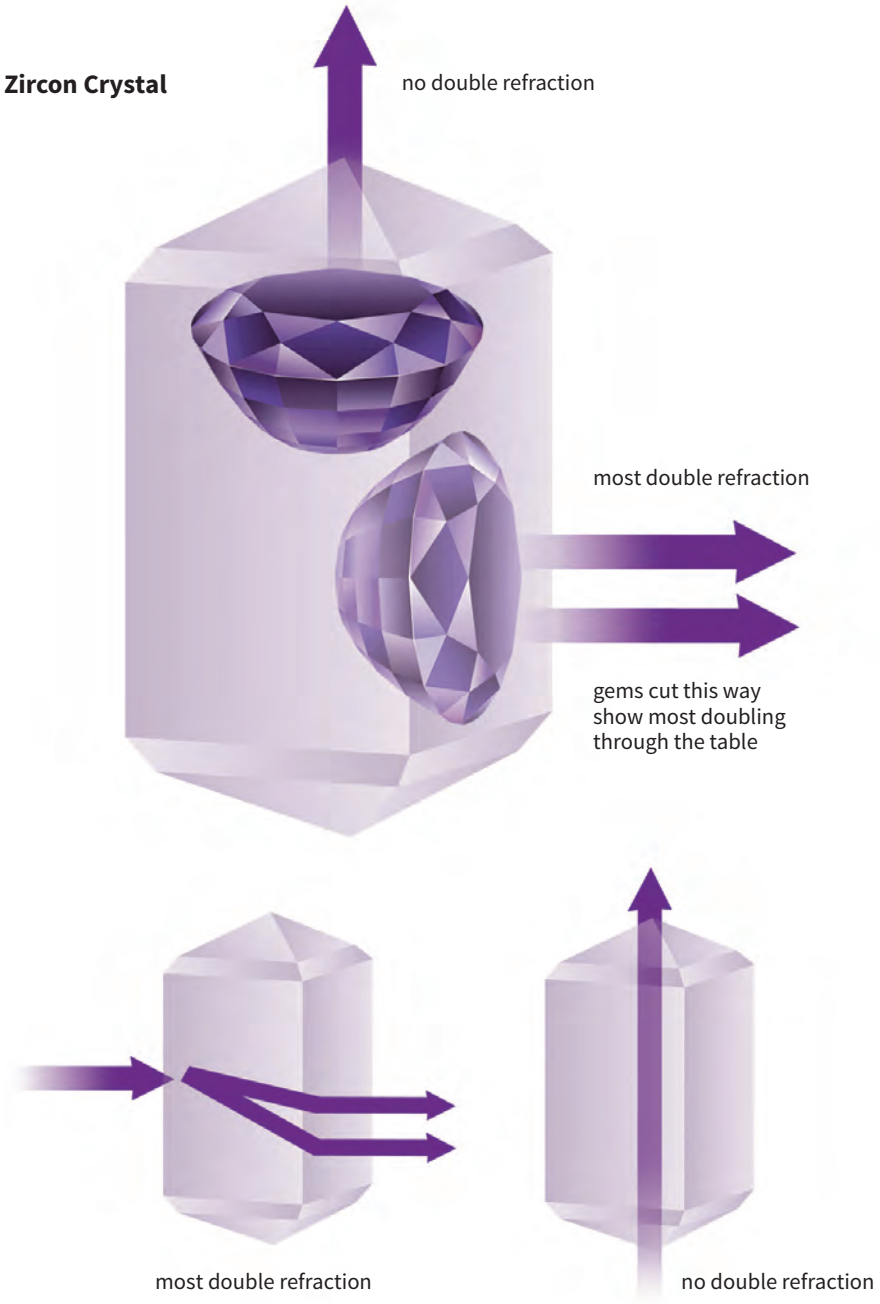
Although it's too soft for gem use, a block of optically pure calcite shows dramatic doubling. If you place a block of calcite over a printed page, you'll see two images of the text. As light enters the calcite, it not only slows down and changes direction, it also splits into two rays. Gemologists call the property that causes this reaction *double refraction*. Double refraction occurs when light entering a crystal encounters differences in atomic structure within the crystal. Most colored stones are doubly refractive.

In certain minerals like spinel, garnet, and diamond, the crystal structure is so symmetrical that there's no splitting of light. Other than refraction and absorption, light traveling through them remains unchanged. Gemologists describe this as *single refraction*.

In some directions, a doubly refractive crystal is less symmetrical than in others and there's maximum double refraction. But in many gems, there's also a direction, called the *optic axis*, where there's no double refraction.

Zircon is doubly refractive, but in one direction—along its length—it's singly refractive, so it doesn't split light. In the past, cutters fashioning colorless zircons took advantage of this singly refractive direction to produce effective diamond imitations. They knew that a cut zircon with its table facet at right angles to the length of the crystal wouldn't show doubling through the crown.

Double Refraction in Zircon

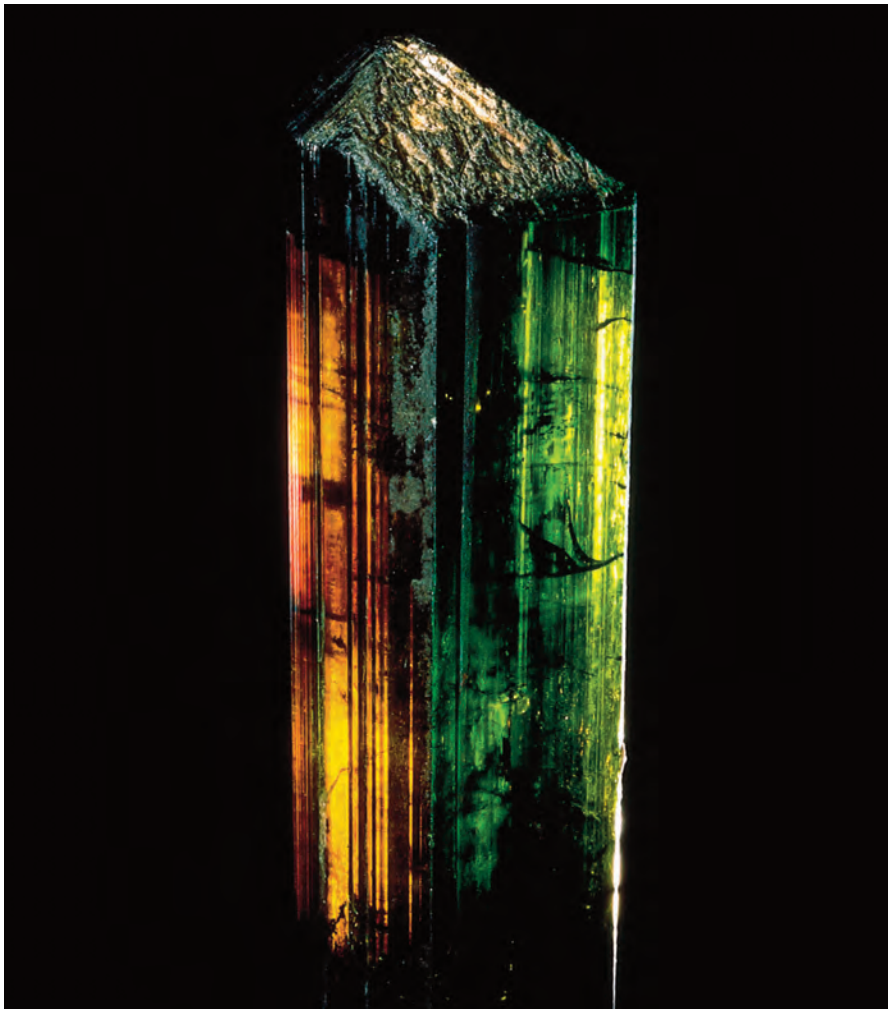


Peter Johnston/GIA

Because of zircon's crystal structure, there's no double refraction parallel to the crystal's length, so gems cut with their table facets at right angles to the crystal's length will show no face-up double refraction. The crystal's structure is least symmetrical at right angles to its length, so that's where doubling is the most obvious.

Tino Hammid/GIA, courtesy David Humphrey

Zircon is doubly refractive but has one singly refractive direction. Cutting zircon to accent that direction results in a beautiful gem.



Nelly Bariand

Very few gems show as much readily visible pleochroism as this 12-cm-high epidote crystal from Pakistan. Directional differences in the gem's structure caused its green and brown pleochroic colors.

Pleochroism

Pleochroism—When a gem shows different bodycolors from different crystal directions.

Although double refraction is an interesting property, it's rarely visible to the eye. But there's one striking property that some doubly refractive gems possess. It's called *pleochroism*. Light traveling down the length of the crystal encounters a different structure than light traveling across it. As a result, the light is absorbed differently. This results in a pleochroic gem—one that shows different colors when viewed along different crystal directions. You can easily see pleochroism in gems like andalusite, tanzanite, and tourmaline.

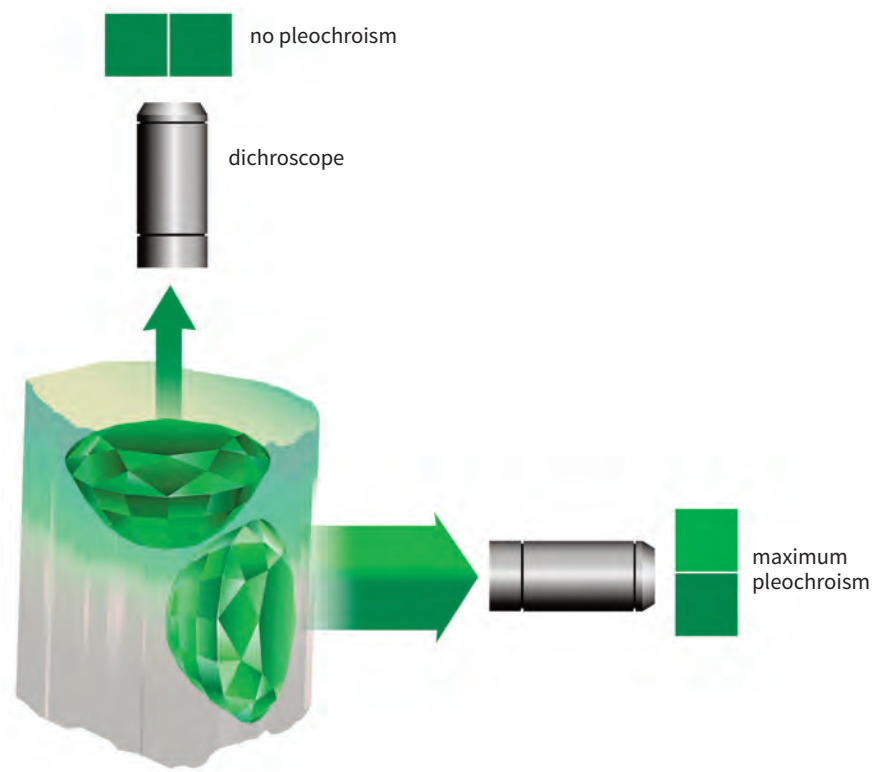
Only doubly refractive gems can be pleochroic. Singly refractive gems can never be pleochroic because their crystal structures are the same in all directions.

KEY CONCEPTS

Only doubly refractive gems can be pleochroic.

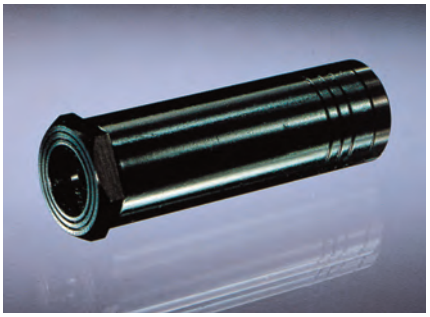
A slender tourmaline crystal looks bright green when you view it from the side. Down its length, it appears to be almost black. This isn't just because you're looking through more material. The tourmaline crystal splits light

Pleochroism in Tourmaline



Peter Johnston/GIA

If you look through a dichroscope down the length of a tourmaline crystal, you won't see any pleochroism. If you look across its length, the instrument will reveal two pleochroic colors.



The dichroscope allows you to see two of a gem's pleochroic colors side by side.

Robert Weldon/GIA, courtesy Gordon Bleck

Some gems are so pleochroic that you can see their pleochroic colors without the help of a dichroscope. This brown tourmaline shows both dark brown and lighter yellowish brown face-up colors.

into two separate rays, except that instead of being colorless, each light ray is a different color. And the crystal actually absorbs light more strongly in some directions than in others.

To get a desirable green gem from a crystal like this, the cutter must facet the gem's table parallel to the crystal's length. If the cutter cuts the table facet at right angles to the crystal's length, the fashioned gem will be too dark, and worth much less as a result.

Gems like tourmaline and sapphire show two pleochroic colors. Other gems, like andalusite, kyanite, tanzanite, and iolite, can show up to three, although only two colors will be visible from any one direction. This is because the differences in atomic structure are more extreme in these gems. The pleochroism in other doubly refractive gems like aquamarine and emerald is usually not readily visible.

Although pleochroism is visible with the unaided eye in some gems, it can be hard to see in many others. A little instrument called the dichroscope helps you to see a doubly refractive gem's pleochroic colors side by side. There's a piece of optically pure calcite at the heart of most dichroscopes. Calcite is extremely doubly refractive, which makes it ideal for viewing pleochroic colors.

KEY CONCEPTS

Dispersion is greater in hi-RI gems than in low-RI gems.

There are some directions in pleochroic gems where you'll see only one color. In blue sapphire, you'll see a pure blue color down the length of the crystal, but both a pure blue and a greenish blue color looking at the side. In sapphire and many other pleochroic gems, dealers prefer one color over the other. Cutters try to orient a cut stone so only the most desirable color shows through the crown.

Dispersion

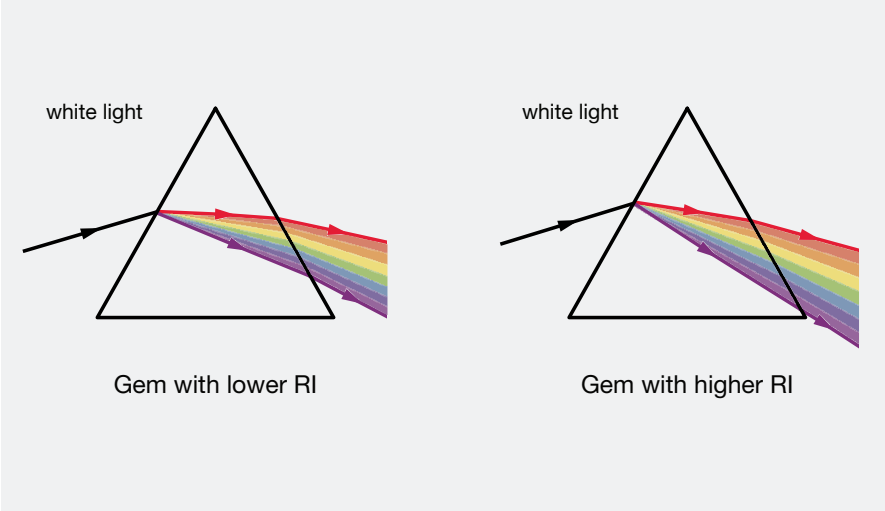
As you've learned, gems refract light to varying degrees. Gemstones with higher RIs slow and bend light more than those with lower RIs. The colored wavelengths of visible light all travel at slightly different speeds, with violet light traveling a bit faster and bending a bit more than red light. Since the difference is extremely small, it isn't normally visible. However, when white light enters a high-RI gem, it slows down and splits into its component colors.

Dispersion—The separation of white light into spectral colors.

Dispersion is the separation of visible light into its spectral colors. In faceted high-RI gems, dispersion causes flashes of different-colored light against the gem's bodycolor. This colorful visible effect of dispersion is called fire.

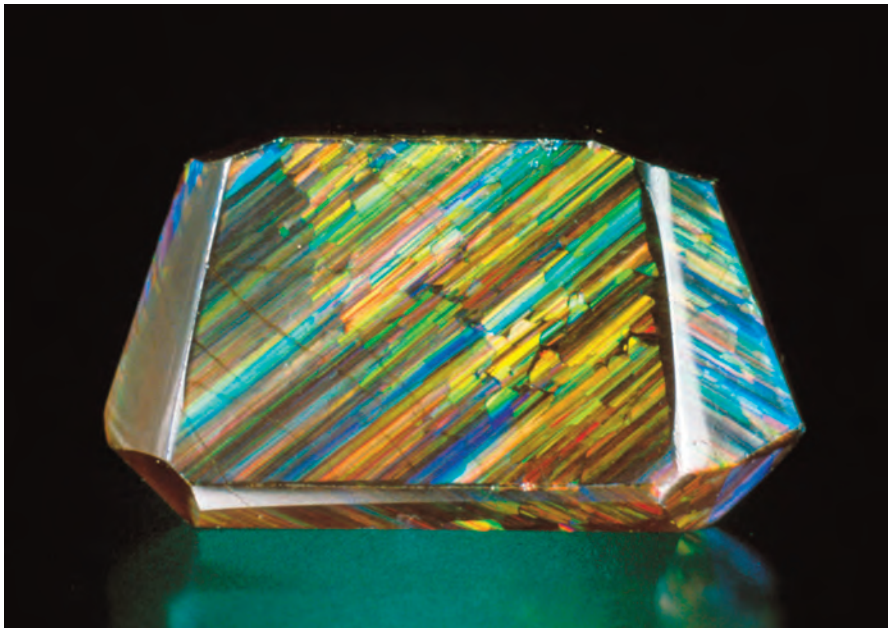
Although fire is highly valued in diamond, it isn't as important in colored stones, where bodycolor often makes it less apparent. But it's still noticeable and adds beauty in high-RI gems like demantoid garnet, sphene, and benitoite.

As you'll see in the next section, some gems have very special optical effects, and cutters have to fashion them carefully to make the most of those effects.



Christopher Cruz/GIA

Gems with higher RIs (right) slow and bend visible light more than gems with lower RIs (left). As a result, high-RI gems separate white light into its spectral colors more effectively and display more fire.



Jeffrey Scovil

Some rare andradite garnets show phenomenal effects. This 4.40-ct. garnet from Mexico has a blaze of parallel color bands caused by light's interaction with the gem's thinly layered structure.

Phenomenal Gemstones

- What causes opal's spectacular colors?
- What causes star and cat's-eye effects in some gems?
- What causes the change-of-color effect in alexandrite and some other gems?

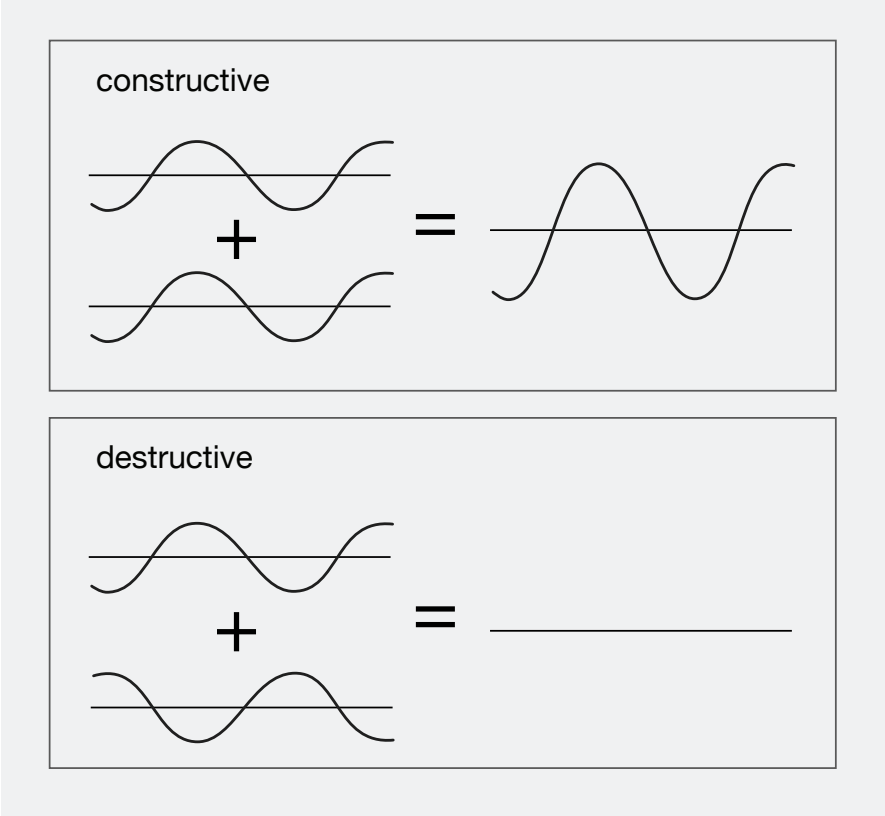
Some gems interact with light in ways that give them unusual optical effects, or phenomena. Phenomenal gems appear at all levels of the gemstone market. Fine opal, fine star corundum, alexandrite, and cat's-eye chrysoberyl are the most rare and valuable phenomenal gems. Moonstone and labradorite are less valuable, but still very attractive. Others, like aventurine quartz, are plentiful and inexpensive.

In some phenomenal gems, the gem's structure causes the phenomenon. In others, inclusions are the cause.

Phenomena Caused by Structure

Moonstone, labradorite, opal, and some pearls owe their phenomena to the way their individual structures interact with light. Each of these gems is made up of minute, repeated layers. Light rays encounter these layers, and are refracted and reflected to varying degrees. The rays interact with each other to produce optical effects. The interaction between light rays is called *interference*.

Interference—Interaction between two light rays with the same wavelengths as they travel along the same path.



Christopher Cruz/GIA

When lightwaves with the same wavelengths travel in the same direction and interact with each other, it's called interference. If their troughs and peaks coincide (top), they reinforce each other and gem colors brighten. If the troughs and peaks occur exactly opposite one another (bottom), the waves cancel each other out and colors become darker.

KEY CONCEPTS

Interference produces either darkness or the brightening of one or more colors.

Interference is just what it sounds like—lightwaves interfering with each other. If the two lightwaves are perfectly synchronized—each wave's peaks and troughs corresponding exactly with the other's peaks and troughs—they reinforce each other, resulting in brighter colors. If the lightwaves are exactly out of phase, with each peak of one wave occurring exactly opposite each trough of the other wave, they cancel each other, resulting in darkness.

Iridescence

Iridescence—A rainbow effect created when light is broken up into spectral hues by thin layers.

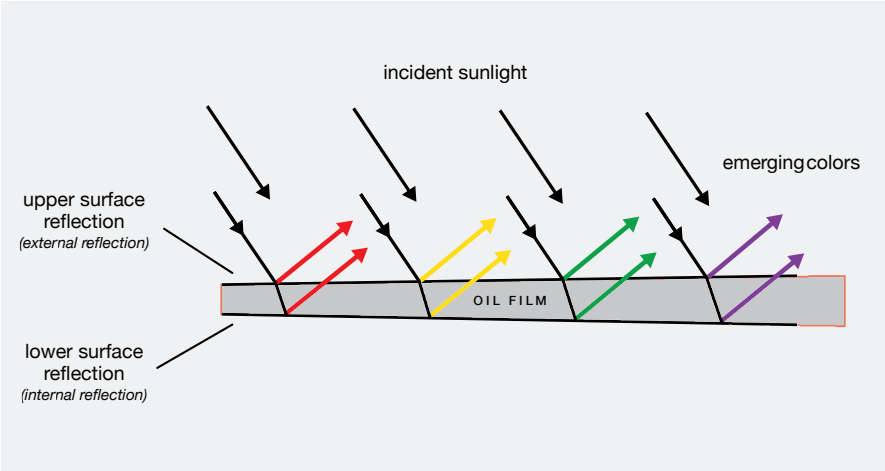
Iridescence is the most common interference phenomenon. It happens when light passes through a thin, transparent film that has a different RI from the surrounding material.

Iridescence is often seen on soap bubbles and in the colorful pattern of a thin film of oil on water. Some light rays are reflected from the top of the film, while some penetrate the surface and are reflected from the bottom. Depending on the RI and the film's thickness, some of the reflected waves travel together and some are out of phase. The out-of-phase wavelengths—and their corresponding colors—cancel each other out.

A soap bubble displays shimmering iridescent patterns because incoming light rays refract and reflect to different degrees when they meet its inner and outer surfaces.

Tino Hammid/GIA, courtesy Carolyn Tyler Designs

Mounted in granulated gold, this free-form fire agate shows attractive iridescence. The phenomenon is a result of the gem's layered structure.



Christopher Cruz/GIA

Reflected lightwaves bouncing off the upper and lower surfaces of a thin film interfere with each other. The colors displayed vary depending on the film's RI and thickness.

Pearl nacre and mother-of-pearl can have just the right structure to display iridescent optical effects. Both are made of very thin layers composed of two different materials: aragonite and conchiolin. Each has a different RI. Iridescence happens when some of the light passing through these thin layers reflects back and combines with other incoming or reflected light rays. A special term, *orient,* is used for pearl iridescence. You'll learn more about it in Assignment 17.

Orient—Iridescence seen in some natural and cultured pearls and mother-of-pearl.

Robert Weldon/GIA, courtesy Marisa Goebel La Belle

Courtesy Empress Abalone Ltd.

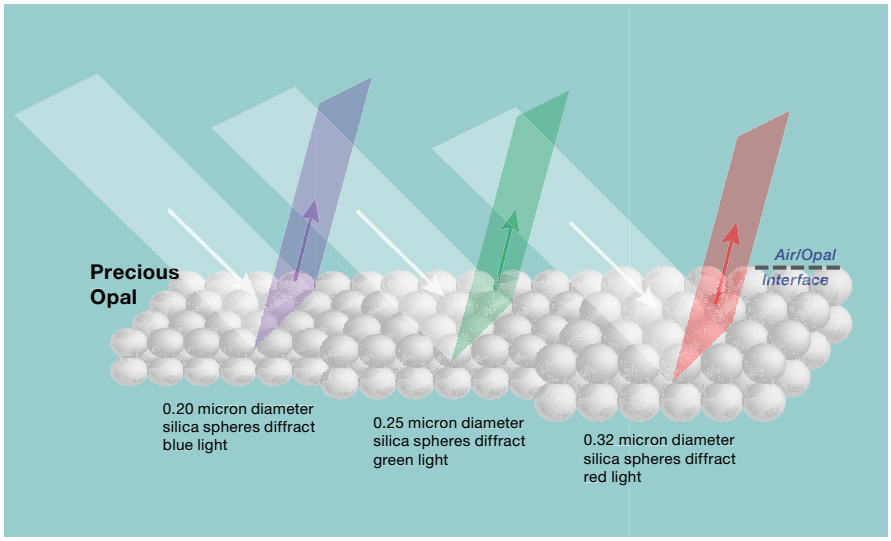
Thin alternating layers interact with light to produce interference effects in pearls. Pearl-trade professionals describe this as orient. The cultured abalone pearls in the necklace (above) and the individual 12-mm to 18-mm Tahitian cultured pearls (left) exhibit attractive orient.

Iris quartz is another iridescent gem. In iris quartz, the iridescence is caused by light passing through a thin layer of air that's trapped within cracks in the crystal.

Play-of-color

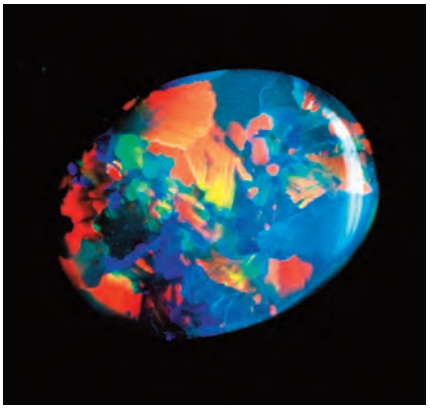
Diffraction—A special kind of interference phenomenon that produces patches of pure spectral colors.

Diffraction is a special type of interference phenomenon. Unlike iridescence, it produces pure spectral colors rather than combinations of several spectral colors. Rather than producing areas of lightness and darkness, it produces the pure spectral hues red, orange, yellow, green, blue, and violet. It occurs in gems that are made up of stacked layers of alternating materials with different RIs like opal and labradorite feldspar.



Christopher Cruz/GIA, reproduced from "Australian Opal – How Did it Form?" by Dr. Simon R. Pecover

Play-of-color results when light interacts with opal's array of tiny stacked silica spheres. The actual colors produced vary with the size of the spheres.



Courtesy Cody Opal

A single precious opal can display all the colors of the rainbow. The gem owes this phenomenon to the interaction of visible light with its remarkably regular internal structure of microscopic silica spheres.

Diffraction is most important in opal. If you could magnify opal's structure with a very powerful microscope, you'd see that it's made up of millions of tiny spheres stacked in layers, forming a regular three-dimensional array. The spheres are made of silica. A slightly different silica and water mixture holds them together. There's a small difference in RI between the spheres and the natural cement.

Light interacts with opal's spheres and silica cement to produce its diffraction phenomenon, called *play-of-color.* Play-of-color features flashes of pure spectral color. The actual spectral colors depend on the size of the silica spheres. Smaller spheres produce blue to green play-of-color and larger spheres produce red.

A single top-quality opal might show many individual color patches. Each color patch displays a pure spectral color—essentially light of only one wavelength. The color in each patch depends on the light orientation and the observer's viewing angle. As the gem is rocked and tilted, the colors change, giving the opal life.

Opal comes in a wider range of quality grades and price levels than other phenomenal gems. It's by far the best known and most popular phenomenal gem, and it's mounted in jewelry to suit every consumer's budget. In Assignment 19, you'll learn more about opal and how to evaluate its play-of-color and overall quality.

John Parrish, courtesy Richard Krementz Gemstones

Opal is the most important phenomenal gem in the colored stone market. It graces jewelry at all price levels.

Play-of-color—The flashing rainbow colors in opal, produced by the interaction of visible light with the gem's microscopic internal structure of stacked silica spheres.

Labradorescence

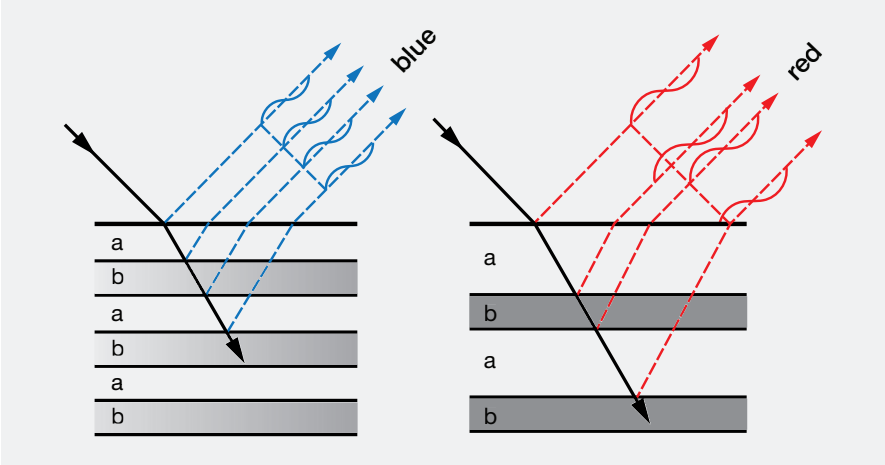
Flashes of color across a dark background make labradorite feldspar instantly recognizable. The flashes are so typical of this gem that it lends its name to the phenomenon: *labradorescence*.

Labradorescence—A broad flash of color in labradorite feldspar that disappears when the gem is moved.

Mike Havstad/GIA

Jeffrey Scovil, courtesy Fred Pough

Even rough labradorite feldspar shows a subtle blue color flash under the right lighting (left). Skilled cutters can release a blaze of phenomenal color from the best material (right).



Peter Johnston/GIA

Labradorite feldspar's diffraction colors vary, depending on the thicknesses and RIs of its alternating layers. As a light beam travels between the layers, it changes direction. It also slows as it passes through the higher-RI layers. Thinner layers (left) tend to produce a blue flash while thicker layers (right) tend to produce a red flash.

Labradorite's phenomenon looks quite different from opal's play-of-color, yet both are caused by diffraction. And, just like opal's play-of-color, labradorite's phenomenon is only visible across a very limited viewing angle. In labradorite, it's caused by alternating layers of two feldspars with different chemical compositions. The colors you see depend on the thickness of the alternating layers and their RIs.

Adularescence

Adularescence—The cloudy bluish white light in a moonstone, caused by scattering of light.

Just as air molecules scatter sunlight to make the sky blue, an irregular arrangement of two different types of feldspar in moonstone scatters incoming light to give the gem its special sheen: a cloudy bluish white light called *adularescence*.

NASA

Robert Weldon/GIA, courtesy David Humphrey

Just as air molecules scatter light to give the sky its blue color (above), moonstone's internal structure interacts with light to produce its characteristic blue sheen, called adularescence (right). In moonstone, light scatters when it encounters the irregular intergrowth of two different types of feldspar.

The scattering happens when light enters the gem in one direction and is deflected in many different directions by the stone's internal structure. Moonstone's structure isn't as regular as the structure of labradorite or opal. It's also made up of alternating layers of two different feldspars, but the layers vary in thickness and regularity. These variations cause the incoming lightwaves to scatter. Moonstone's internal structure causes the blue and violet wavelengths of white light to scatter more strongly than red, orange, yellow, and green. These wavelengths are transmitted through the gem, while blue and violet bounce back to the observer and show up as the gem's characteristic adularescence.

Chatoyancy—Bands of light in certain gems, caused by reflection of light from many parallel, needle-like inclusions or hollow tubes.

Milk and honey—A two-toned effect seen when a chatoyant gem is positioned at right angles to a light source.

Phenomena Caused by Inclusions

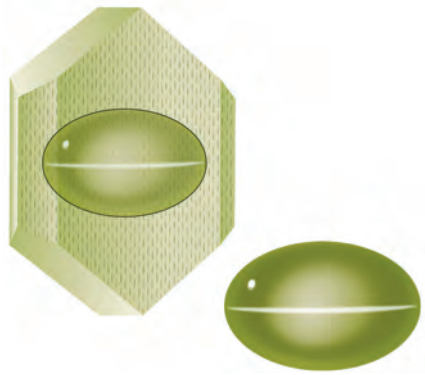
Most of the time, inclusions detract from a gem's beauty. However, if they're just the right kind and in just the right position, they can cause spectacular optical effects. These effects, produced by the reflection of light rays, can make a gem look like a cat's eye, produce a bold star, or give a gem glittery sparkle.

Chatoyancy

Cat's-eye chrysoberyl is the best-known and most highly valued cat's-eye gem. It's a connoisseur's gem: Fine stones grace men's rings and cufflink sets. The gem's striking "eye" is caused by parallel needle-like inclusions or fine hollow tubes that—when the gem is cut correctly—reflect light to create a silky sheen called *chatoyancy*.

Cutters produce the best cat's-eye gems by cutting the cabochon's base parallel to the gem's inclusions. This cutting style concentrates the sheen across the dome of the cabochon.

In addition to chatoyancy, fine cat's-eye gems, especially chrysoberyl, show two other optical effects. The first is known as *milk and honey*. If you place a light source at right angles to the cat's-eye, one side of the stone turns milky while the other retains its honey color.



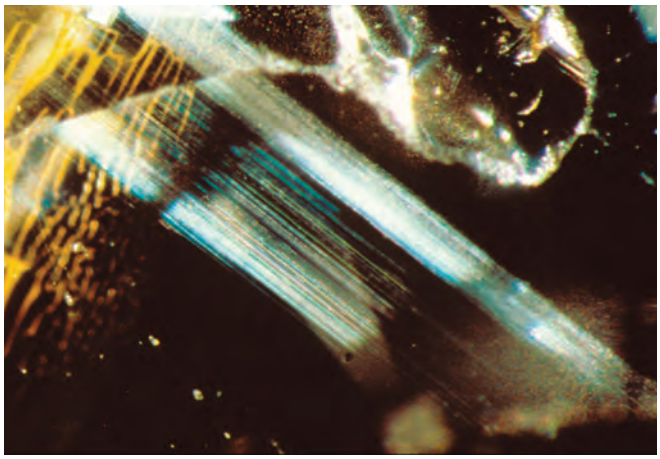
Peter Johnston/GIA

It's important to orient chatoyant chrysoberyl rough carefully to get the best fashioned stones. Because the inclusions are parallel to the crystal's length, cutters must cut across the width to display a cat's-eye in the finished gem's longest dimension.

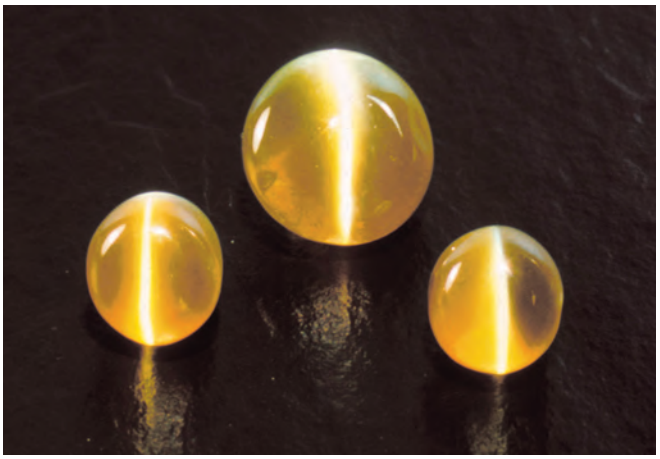
To produce the other effect, rotate the cat's-eye chrysoberyl between two light sources. Each light source produces a separate chatoyant band and its eye appears to open and close as the gem turns.

Tourmaline and quartz can also display chatoyancy, but neither can match fine cat's-eye chrysoberyl's appearance or value. You'll learn how to assess cat's-eye chrysoberyl in Assignment 21.

Chatoyancy can also be artificially created by carving parallel grooves on a gem material's surface. The resulting bright band is an effective imitation of natural chatoyancy. Such imitations are usually fashioned with a cabochon top and a flat base.



John Koivula/GIA

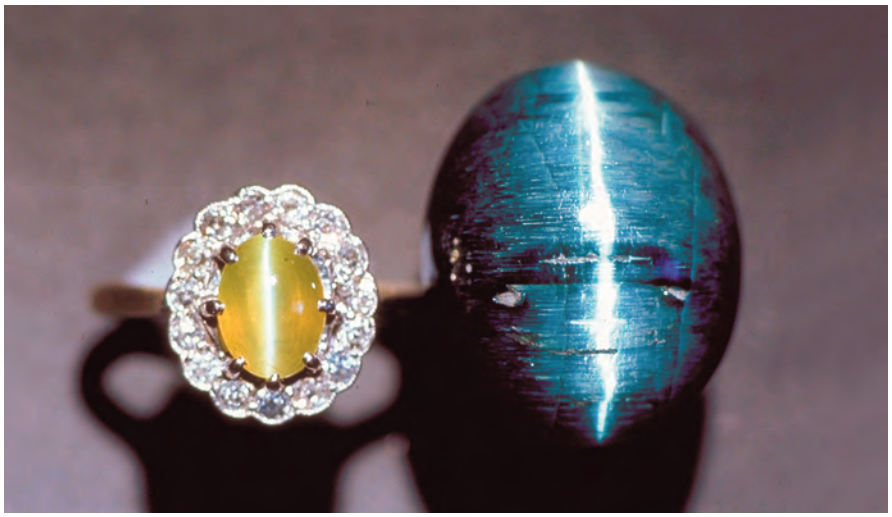


Bart Curren/ICA

Like light reflecting off the threads on a spool, cat's-eye chrysoberyl's sharp reflection arises from light's interaction with internal parallel inclusions (left). Fine needles or hollow tubes (right) cause the reflections when the gem is correctly cut.

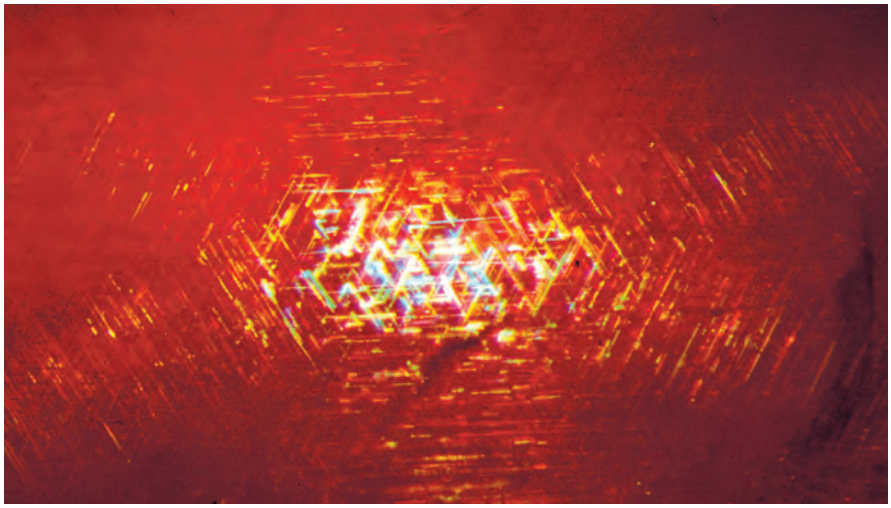
Robert Weldon/GIA, courtesy Gordon Bleck

When light hits at just the right angle, cat's-eye chrysoberyl shows an optical effect that gem experts describe as milk and honey.



Alan Jobbins

The cat's-eye chrysoberyl on the left demonstrates the way this gem outclasses all other chatoyant gems. By comparison, the tourmaline's cat's-eye is less focused. This is because the hollow tubes that cause its reflections are coarser.

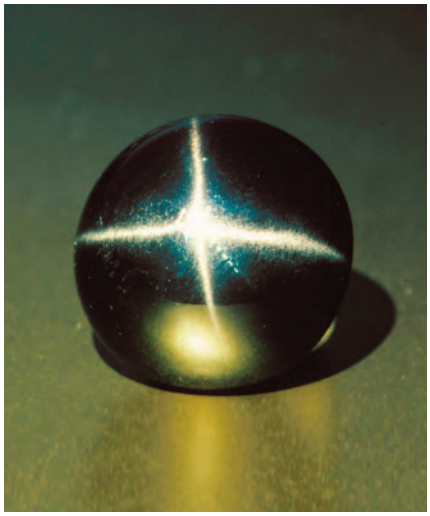


John Koivula/GIA

This ruby's star is the result of three intersecting sets of rutile needle inclusions.

Courtesy Krashes & Dirnfeld, New York

This fine 21.89-ct. Burmese star ruby shows an almost perfect combination of sharp star and nearly transparent red bodycolor.



Mike Havstad/GIA

Star diopside is easily distinguished from black star sapphire by its four-rayed star. Its phenomenon is a result of intersecting magnetite inclusions.

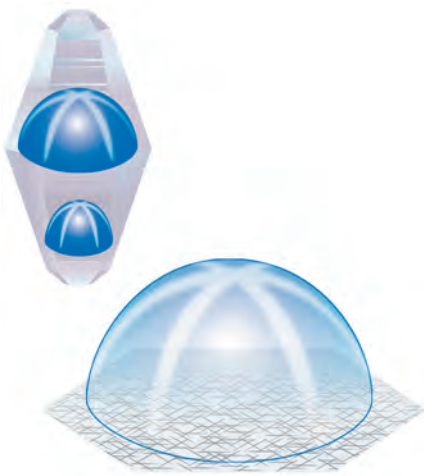
Tino Hammid/GIA

If correctly fashioned, some spinel can show a six-rayed star. A cutter took advantage of the twin plane running vertically down the center of this stone to cut a sphere with a double star.

Asterism

Some sapphire crystals contain a multitude of tiny rutile needles. Each little inclusion is parallel to one of the sapphire crystal's six sides. Because opposite faces of the sapphire crystal are parallel, the inclusions intersect in three directions. When there are enough of these tiny needles, they reflect the light just like a cat's-eye does, except there are three sets of reflections rather than one. In sapphire, the three sets intersect to form a six-rayed star. Gemologists call this phenomenon *asterism*.

Asterism—Crossing of chatoyant bands, creating a star in the dome of a cabochon.



Peter Johnston/GIA

In some corundum, three sets of intersecting inclusions can produce a star if the rough is correctly cut. To achieve a properly centered star, the cutter must orient the cabochon's base parallel to the plane of these inclusions, which is at right angles to the crystal's length.

Several gem species, including garnet, diopside, and spinel, show asterism. But star sapphires and star rubies are the most valued. The best star corundum is semitransparent, but most star rubies and sapphires are translucent or opaque. Star corundum is judged by color and by the sharpness and positioning of its star.

To show asterism at its best, cutters try to place the reflective inclusions parallel to the base of the cabochon. Ideally, the star should be sharp and distinct, with straight, even rays intersecting at the top of the stone.

Some star stones are mere gemological curiosities, like dull gray or black cabochons with poor stars. Others, like exceptional star rubies and star sapphires with sharp stars and fine color, are so spectacular that buyers compete eagerly for them. You'll learn how to judge star corundum in Assignment 14.

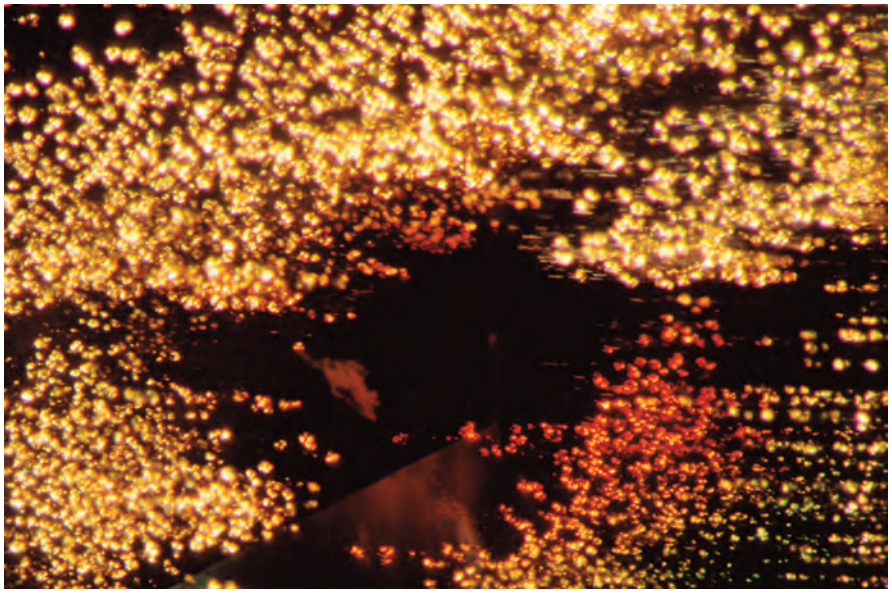
Aventurescence

Aventurescence—A glittery effect caused by light reflecting from small, flat inclusions within a gemstone.

A sunstone feldspar cabochon sparkles with thousands of tiny reflections as it moves in the light. This phenomenon, called *aventurescence*, is caused by light reflecting from many small but eye-visible plate-like inclusions in the stone. When the stone is rotated in the light, each inclusion reflects the light back to the viewer.

In sunstone feldspar, copper or sometimes hematite inclusions cause aventurescence and suffuse the gem with golden color. In aventurine quartz, spangles of green mica produce the glittery effect and also give the gem its color.

Tino Hammid/GIA



John Koivula/GIA

A sunstone feldspar cabochon catches the eye with its array of glittering reflections (left). Magnification (above) reveals a multitude of tiny, randomly oriented inclusions—usually copper or hematite—that cause the attractive aventurescence.

Tino Hammid/GIA

Tino Hammid/GIA

Although alexandrite chrysoberyl is the best-known color-change gem, garnet can offer an attractive—and less costly—alternative. These two color-change garnets from Madagascar have an intense orange color under incandescent light (top), but they look brownish under fluorescent light (bottom).

Christie's Images Inc.

When it displays strong color change—from red under incandescent light to green under fluorescent light—alexandrite chrysoberyl is one of the most sought-after phenomenal gems. A collector might pay more than $120,000 for this ring with its 13.21-ct. alexandrite.

Color Change

Fine alexandrite chrysoberyl is featured in exclusive auction catalogs, with buyers clamoring for the best specimens. This allure is due partly to its romantic history—Russian czars prized it—and partly to its fascinating phenomenon.

As in ruby and emerald, traces of the transition element chromium cause alexandrite's color. Alexandrite allows almost equal amounts of red and green light to pass through, but it absorbs light most strongly in the middle of the visible spectrum.

Because the gem's absorption is closely balanced between red and green, its color varies with the type of lighting it's viewed under. When an alexandrite is under lighting that's rich in red—like an incandescent light bulb—the gem looks like ruby. If it's under lighting that's rich in blue and green—like a fluorescent light—the gem looks like emerald. This phenomenon is called *color change*.

Even the best alexandrite can't match the finest ruby or emerald in color. It's the gem's striking red to green color change that draws buyers. Although alexandrite is the most valued color-change gem, some others, like sapphire, spinel, and garnet, can also show this effect.

Color change—A distinct change in gem color under different types of lighting.

Phenomenon	Cause	Gem materials
Iridescence	Interference: Interaction of visible light rays with a thin film or thin structure in—or on—a material with a different RI. Produces interference colors (like oil on water)	Pearl, mother-of-pearl
Play-of-color **Labradorescence**	Diffraction: Interaction of visible light with regularly layered structures smaller than visible wavelengths of light. Produces pure spectral colors that change when the stone is rotated.	Opal with play-of-color, labradorite feldspar
Adularescence	Scattering: Interaction of visible light with irregularly distributed structures smaller than visible wavelengths of light. Billowy, floating sheen	Moonstone feldspar
Chatoyancy	Reflection: Interaction of visible light with oriented parallel needle-like or plate-like inclusions or structures larger than visible wavelengths of light. Single set of parallel oriented inclusions or structures that produce a mobile band of light like a cat's eye on the surface of a cabochon.	Chrysoberyl, quartz, tourmaline, diopside
Asterism	Reflection: Interaction of visible light with oriented parallel needle-like or plate-like inclusions or structures larger than visible wavelengths of light. Two or more sets of oriented inclusions or structures that intersect to produce a star on the surface of a cabochon.	Corundum, garnet, spinel, diopside
Aventurescence	Reflection of light from large, eye-visible, plate-like inclusions, causing glittery reflections when the stone is moved under reflected lighting.	Aventurine quartz, sunstone feldspar, goldstone glass
Color change	Bodycolor changes when the illumination is switched from sunlight or fluorescent light to incandescent light. Gem's absorption is closely balanced between red (warm) and green (cool), and its color varies with the type of lighting.	Alexandrite chrysoberyl, color-change corundum, color-change garnet

In this assignment, you've learned how gems interact with visible light to produce color and striking visible effects. You've also seen that a gem's optical properties—color, pleochroism, or one of many phenomena—can have a dramatic effect on its desirability and value. In Assignment 5, you'll see how synthetic gem manufacturers use their knowledge of these interactions to create convincing gem alternatives. Then, in Assignment 6, you'll see how treatment professionals work with natural gems' optical properties to improve their color or enhance their phenomenal effects and make them more marketable.

KEY CONCEPTS

Color is the most important contributing factor to a colored stone's desirability, marketability, and value.

Light is a form of radiant energy that travels in waves.

Visible light is a small portion of the electromagnetic spectrum.

White light is a combination of the spectral colors red, orange, yellow, green, blue, and violet.

Most gem color is caused by selective absorption, which is influenced by chemical composition and crystal structure.

Interaction of electrons with visible light causes most selective absorption related gem colors.

Chromium causes the most desirable red and green gem colors.

Iron causes a greater variety of gem colors than any other transition element.

Valence differences can cause variations in color intensity in the same gem material.

Crystal structure variations result in the same transition element causing different colors in different gems.

Colors produced by charge transfer are much stronger than colors caused by dispersed ions.

Treatment can alter or initiate some color-causing charge transfer reactions.

The presence of transition elements adds new energy levels within a gem's band gap, helping electrons absorb some visible light wavelengths.

Irradiation produces color in gems by creating color centers.

Color centers allow selective absorption to take place by lowering the energy required for electrons to make transitions in the band gap.

Heat treatment removes unwanted colors by destroying the color centers that cause them.

Only doubly refractive gems can be pleochroic.

Dispersion is greater in hi-RI gems than in low-RI gems.

Interference produces either darkness or the brightening of one or more colors.

Key Terms

Absorption spectrum—A pattern of dark vertical lines or bands shown by certain gems when viewed through a spectroscope.

Adularescence—The cloudy bluish white light in a moonstone, caused by scattering of light.

Allochromatic—A gem colored by trace elements in its crystal structure.

Asterism—Crossing of chatoyant bands, creating a star in the dome of a cabochon.

Aventurescence—A glittery effect caused by light reflecting from small, flat inclusions within a gemstone.

Charge transfer—The movement of electrons back and forth between ions, causing the selective absorption of light.

Chatoyancy—Bands of light in certain gems, caused by reflection of light from many parallel, needle-like inclusions or hollow tubes.

Color center—A small defect in the crystal structure of a material that can absorb light and give rise to a color.

Color change—A distinct change in gem color under different types of lighting.

Diffraction—A special kind of interference phenomenon that produces patches of pure spectral colors.

Dispersion—The separation of white light into spectral colors.

Double refraction—When a gem's crystal structure splits light into two rays that each travel at a slightly different speed and direction.

Doubling—The appearance of double images of a gemstone's facet junctions on the side opposite the viewer.

Fluorescence—Emission of visible light by a material when it's stimulated by ultraviolet or X-ray radiation.

Idiochromatic—A gem colored by an element that is an essential part of its chemical composition.

Interference—Interaction between two light rays with the same wavelengths as they travel along the same path.

Intervalence charge transfer—A process where two transition elements with different valences exchange electrons to selectively absorb light.

Iridescence—A rainbow effect created when light is broken up into spectral hues by thin layers.

Irradiation—A treatment in which a gem is exposed to radiation to change or improve its color.

Labradorescence—A broad flash of color in labradorite feldspar that disappears when the gem is moved.

Milk and honey—A two-toned effect seen when a chatoyant gem is positioned at right angles to a light source.

Optic axis—Direction of single refraction in a doubly refractive gem.

Orient—Iridescence seen in some natural and cultured pearls and mother-of-pearl.

Phosphorescence—Continued emission of visible light after UV or X-ray stimulation stops.

Play-of-color—The flashing rainbow colors in opal, produced by the interaction of visible light with the gem's microscopic internal structure of stacked silica spheres.

Pleochroism—When a gem shows different bodycolors from different crystal directions.

Refraction—Change in speed and possible change in direction of light as it travels from one material to another.

Selective absorption—Process by which a material absorbs some components of visible light and transmits others.

Single refraction—When a gem's crystal structure doesn't change incoming light other than by refraction and absorption.

Transition elements—Elements that can selectively absorb some wavelengths of visible light and produce color in gems.

Wavelength—The distance between two adjacent high points of an energy wave.

Questions for Review

- Why are some gem colors more rare and more valuable than others?
- Which element produces the brightest reds and greens?
- How can the same impurity element cause different colors in different gems?
- How does a gem's interaction with light cause its color?
- How does crystal structure influence the way a gem interacts with light?
- What causes double refraction?
- What causes pleochroism?
- What causes opal's spectacular colors?
- What causes star and cat's-eye effects in some gems?
- What causes the change-of-color effect in alexandrite and some other gems?

Synthetics and Imitations

5

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Welcome to *Colored Stones* Assignment 5. With the knowledge you gain from this assignment, you'll be able to:

- Understand the history and current role of synthetic colored stones in the market.
- Communicate the major gem synthesis methods.
- Identify the basic characteristics of modern synthetic colored stones.
- Explain how natural, synthetic, and non-gem materials can act as gem imitations.
- Recognize the importance of disclosure when marketing synthetic gems and imitations.

Fred Ward/GIA

A scene from a flame-fusion laboratory in Switzerland shows the intense heat needed to grow synthetic gem crystals by this method.

Synthetics and Imitations

Long ago, people regarded natural gems as beautiful objects with magical properties that shouldn't be tampered with. This attitude changed in the eighteenth century, when natural gem structure and composition became less mysterious. As scientific research began to uncover gems' physical properties, chemists began to grow crystals of simple composition and to experiment with growing more complex ones.

By the end of the nineteenth century, crops of crystals that duplicated the appearance and physical makeup of many natural gems were being developed in scientists' laboratories. Today, electronics firms use manmade crystals in lasers and communication devices. And laboratory-grown gem crystals that are large and attractive enough for use in jewelry continue to appear on the market as alternatives to natural gems.

KEY CONCEPTS

Knowing whether a gem is natural or synthetic is crucial when buying or selling colored stones.

Imitations can be made of a variety of materials, including natural or synthetic versions of other gems.

Nicholas DelRe/GIA

The synthetic rubies in this beautiful period ring resulted from an early version of a gem synthesis method called flame fusion.

Courtesy Apple

Synthetic sapphire screens are tough enough for use in smaller devices like some Apple watches, but fail "drop tests" when used in tablets and other large devices.

Synthetic gem—A laboratory creation with essentially the same chemical composition, crystal structure, and properties as its natural counterpart.

Imitation gem—Any material that looks like a natural gem and is used in its place.

Synthetic gems are made in factories and laboratories, but they have essentially the same crystal structure and chemical composition as their natural counterparts. At first sight, a synthetic resembles a natural gem in color, weight, and a host of other characteristics. Upon closer inspection, however, gemologists can detect clues that help them tell the difference between synthetic and natural crystals.

Knowing whether a gem originated in a mine or a laboratory is crucial for anyone who buys or sells colored stones. Knowing a stone's origin also helps determine its value. Although the cost of production varies widely from one synthetic to another, synthetics in general are less expensive than their natural gem counterparts. When synthetics are sold as natural gems—on purpose or by accident—the deception impacts everyone.

Synthetic colored stones are not the only materials that replace natural gems in jewelry. For as long as people have admired the color and brilliance of gems like sapphire, emerald, and ruby, they have looked for ways to imitate them. *Imitation gems* can be made of a variety of materials, including glass, plastic, and assembled combinations of natural and artificial materials. In fact, any material that is not the natural colored stone but that looks like it can be considered an imitation and used in its place.

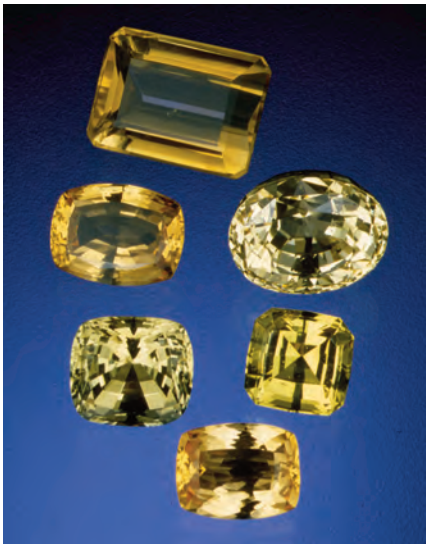
An imitation can also be a synthetic or natural version of a different gem. Throughout history, natural gems have been used in place of other natural gems—usually more expensive ones—of the same color. In fact, before scientists uncovered their chemical and structural differences, all red gems were called rubies, all blue gems were called sapphires, and all green gems were called emeralds. In modern times, blue synthetic spinel might be used as a substitute, not for natural spinel, but for natural aquamarine.

Courtesy Century Time Gems

The hardness of synthetic corundum makes it ideal for making scratch-resistant watch-face covers. It also has many industrial applications.

Gagan Choudhary/Gem Testing Lab, Jaipur, India

Imitation gems are made of many different materials, including glass. This glass imitation of emerald appeared in the 1990s.



Tino Hammid/GIA

Gems of the same color can substitute for one another. The yellow sapphire at the upper right is the most expensive gem. The others—citrine, hessonite, tourmaline, beryl, and topaz—can all be effective alternatives.

Understanding the most common types of synthetics and imitations will help you recognize the differences between them. These differences influence not only their relative cost, but also their relative effectiveness as colored gem substitutes.

Synthetic Processes and Their Products

- What are the two main categories of synthetic-gem production methods?
- What are some differences between products of melt and solution processes?
- Why is quartz synthesis important?
- What are some basic differences between synthetic and natural gems?

Contrary to what you might think, the word "synthetic" does not mean fake. Instead, the term comes from the Greek for "to put together." People "build" or, more accurately, "grow" synthetic crystals. They do this by using chemicals that, given the proper environment, arrange themselves into crystals of essentially the same structure as crystals that grow without human intervention.

Other terms used by the trade to describe synthetics include "laboratory-created," "manufactured," and "manmade." Some manufacturers prefer the term "cultured," but it's not widely accepted.

There are many processes for making synthetic colored stones. Some synthetic gems can only be made using a single process. But, as is often the case in nature, some synthetic gem types—corundum, for example—can result from more than one process. In fact, synthetic corundum can be derived from the greatest number of processes.

Robert Weldon/GIA

Synthetic corundum can be made using a wide variety of processes. This synthetic ruby was made using the flux method.

The synthetic stones in class rings are often manufactured by a low cost, high volume process. Rapid production of a large quantity of synthetic gemstones helps fill the need for affordable mass-produced jewelry.

Nicholas DelRe/GIA

A high cost, low volume process resulted in this ring's synthetic emerald. Such processes require expensive investments in equipment and time.

The development of synthetic gems often arises out of demand for their natural counterparts. For example, natural corundum has long been known for its practical applications. Jewelers used it for bearings in mechanical timepieces more than 300 years ago. The first synthetic corundum—a flux-grown ruby—was produced in 1873. Those early synthetic sapphires and rubies were used for watch jewels and set in jewelry.

Today, the use of synthetic corundum in jewelry is secondary to its industrial and technological uses. In the past few decades, synthetic sapphire production increased from less than 100 metric tons per year—when output centered on gem use—to around 1,000 metric tons, mostly for non-jewelry applications.

As growers continue to develop new processes for the production of synthetic gemstones, their goal is always to improve the color, clarity, or other characteristics of the product. Sometimes, they also reduce manufacturing costs. But sometimes a more expensive process offers improvements in synthetic gem appearance that make the increased cost worthwhile.

Knowing the process that produced a particular synthetic gem is helpful when buying synthetics because process can determine value. In general, synthetic production processes fall into two value categories:

- Low cost, high volume
- High cost, low volume

Low cost, high volume synthetic processes are both quick and inexpensive. They produce synthetic colored stones that generally retail for only a few dollars a carat. High cost, low volume processes require more expensive investments in equipment and time. As a result, synthetics from these processes might retail for hundreds of dollars per carat.

Manufacturers might choose the more expensive and labor-intensive processes for a number of reasons: because the resulting synthetics look more attractive, because they more closely resemble natural gems, or because the process is the only one that produces a particular synthetic.

Melt and Solution

During the twentieth century, researchers in science and industry developed a multitude of crystal growing techniques. Many of the methods still in use, however, are reserved for experimental purposes or advanced technological applications. Most methods used for synthetic colored stone production today derive from two main types of processes, known as *melt* and *solution*.

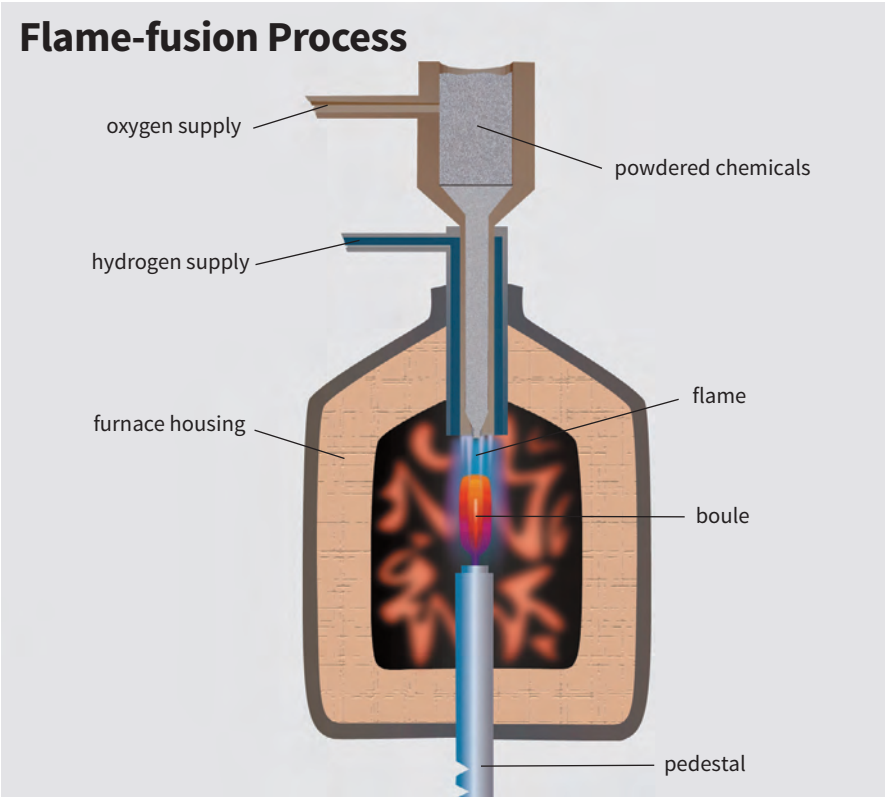
Melt Processes

Like a cook assembling ingredients for a recipe, a crystal grower making synthetic gemstones by a melt process starts with a mixture of chemical elements or compounds. The mixture must first be melted and then carefully cooled so the largest possible single crystals form as the material solidifies. The mixture contains the same ingredients as the synthetic crystals being made, so the resulting crystal has the same composition as the melt.

The two most common melt processes are *flame fusion* and *pulling*.

Flame Fusion

Flame fusion has been around since the late 1800s. Auguste Verneuil (vair-NOY) produced the first commercially successful synthetic ruby in the early 1900s. (The process is also known as the Verneuil method.) The basic steps are much the same today as they were then. Powdered chemicals drop through a high-temperature flame onto a slowly sinking and rotating pedestal. The melted chemicals cool, then crystallize (solidify). The synthetic crystal forms an elongated mass, called a *boule* (BOOL), that can measure up to 23 cm (9 inches) long and about 2.5 to 5.0 cm (1 to 2 inches) in diameter.



Peter Johnston/GIA

KEY CONCEPTS

The process used to produce a synthetic gem can determine its value.

Advances in synthetic crystal growth have been driven mostly by industrial and research demands.

Most synthetic gem crystals are produced by either a melt or a solution process.

Melt process—A synthetic-crystal growth method in which the chemical mixture is melted, then recrystallized.

Solution process—A growth method in which the synthetic crystal grows from a dissolved chemical mixture, sometimes at high temperature and pressure.

Flame fusion—A process in which powdered chemicals are dropped through a high-temperature flame onto a rotating pedestal to produce a synthetic crystal.

Pulling—A process in which the lab-grown crystal grows from a seed that is dipped into a chemical melt and then pulled away as it gathers material.

Boule—A cylindrical synthetic crystal produced by a melt process.

In the flame-fusion process, powdered chemicals drop through a high-temperature flame onto a slowly sinking and rotating pedestal. As the chemicals cool and crystallize, they produce a synthetic crystal.

Flame Fusion

Terri Weimer/GIA

Flame fusion is the most important and highest-volume gem synthesis method. These are boules of flame-fusion synthetic color-change and colorless sapphire and blue spinel.

Robert Weldon/GIA, courtesy Kurt Nassau

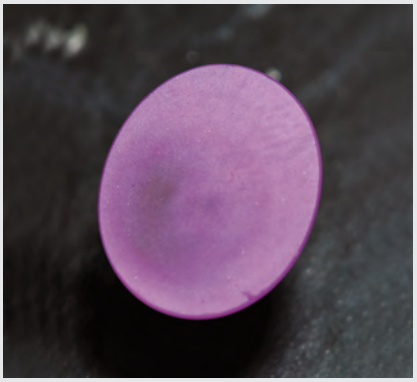
Before Verneuil's flame-fusion process, other researchers had tried similar methods to grow synthetic rubies. Some claimed to use natural corundum sand as a seed material. These synthetic rubies were produced by a variety of processes including the Verneuil method.

Robert Weldon/GIA, courtesy Kurt Nassau

These synthetic rubies were grown by pre-Verneuil flame-fusion techniques. On the right is a boule of synthetic ruby grown in the US by one of Verneuil's former assistants around 1900. On the left is a faceted synthetic ruby that was produced around 1885 by a multi-stage flame-fusion process.

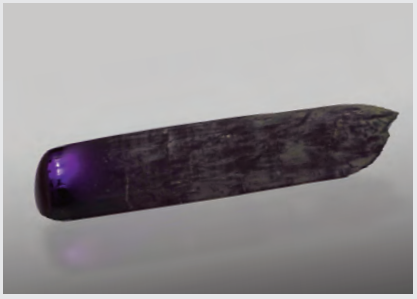
Eric Welch/GIA

Synthetic star corundum typically combines excellent bodycolor with a sharp, well-centered star.



Eric Welch/GIA

Unlike natural star corundum, which cutters typically fashion as double cabochons with weight-saving bases, synthetic stars have flattened bases.



Terri Weimer/GIA

Synthetic color-change sapphire takes second place in production levels, after synthetic ruby.

Eric Welch/GIA

Eric Welch/GIA

Synthetic color-change sapphire is reddish purple under incandescent light (left). Under fluorescent light, it's typically bluish violet (right).

Maha Tannous/GIA

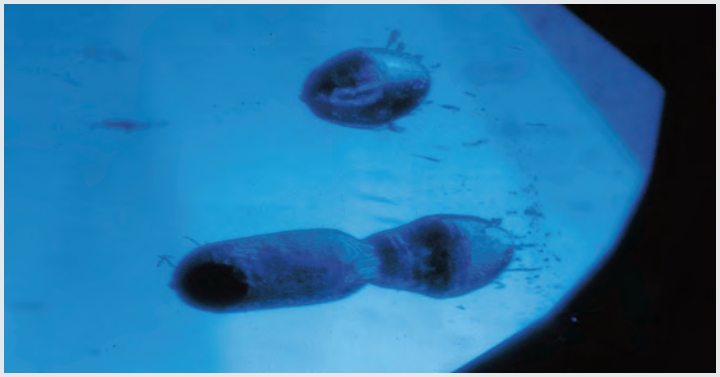
These flame-fusion synthetic sapphires were fashioned to imitate imperial topaz.

Eric Welch/GIA

Traces of cobalt give flame-fusion synthetic spinel its blue color.

Eric Welch/GIA

While it's not an especially convincing blue sapphire imitation, synthetic blue spinel can be a good imitation of aquamarine.



John Koivula/GIA

Gas bubbles are characteristic inclusions in flame-fusion synthetic spinel.

Terri Weimer/GIA

Flame-fusion synthetic pink spinel is sold in the trade under the name Rose de France. It's used to imitate a variety of materials, including pale amethyst.

Terri Weimer/GIA

Some flame-fusion synthetic spinel boules have nearly straight sides and square, rounded cross-sections. Viewed in its long direction, this flame-fusion synthetic pink spinel boule displays that characteristic form.

Robert Weldon/GIA

Synthetic ruby is often produced by flame fusion.

Alan Jobbins

Flame fusion produces an elongated mass, or boule, from cooled and crystallized chemicals.

Flame fusion was the first method to result in a marketable synthetic—Verneuil's gem-quality ruby. Because of its efficiency, flame fusion is still the main method used to synthesize gems. Flame-fusion gem crystals grow quickly (about 1 cm, or 0.40 in., per hour) and are inexpensive to make. A large boule can yield many cut stones at one time, making each individual stone relatively inexpensive. These factors make flame fusion a low cost, high volume process and allow manufacturers to retail flame-fusion products at only a few dollars per carat.

Synthetic colored stones made by flame fusion include ruby and star ruby, sapphire and star sapphire, and spinel. Synthetic rutile, which has been used as a diamond imitation, is also made by the flame-fusion method.

Some flame-fusion corundum displays very distinct curved growth and might require careful orientation during the cutting process. Blue flame-fusion material is the most difficult and most expensive to grow. Many producers who tried growing it have left the industry or switched to pink, red, or colorless production. Some flame-fusion facilities that started out growing gem crystals have switched to high-purity colorless sapphire for industrial applications. This has resulted in reduced supplies of many gem-quality synthetic sapphire colors.

Production of flame-fusion sapphire began in Europe, but spread to new locations as demand for industrial applications grew. Dozens of new crystal-growth facilities have emerged around the globe, especially in Asia, which has vastly increased capacity.

Pulling

In 1960, Theodore Maiman demonstrated the first optical laser, which used a Verneuil-grown ruby crystal fashioned into a rod. However, researchers found that flame-fusion crystals weren't pure enough for commercial lasers. This prompted adoption of the pulling, or "pulling from

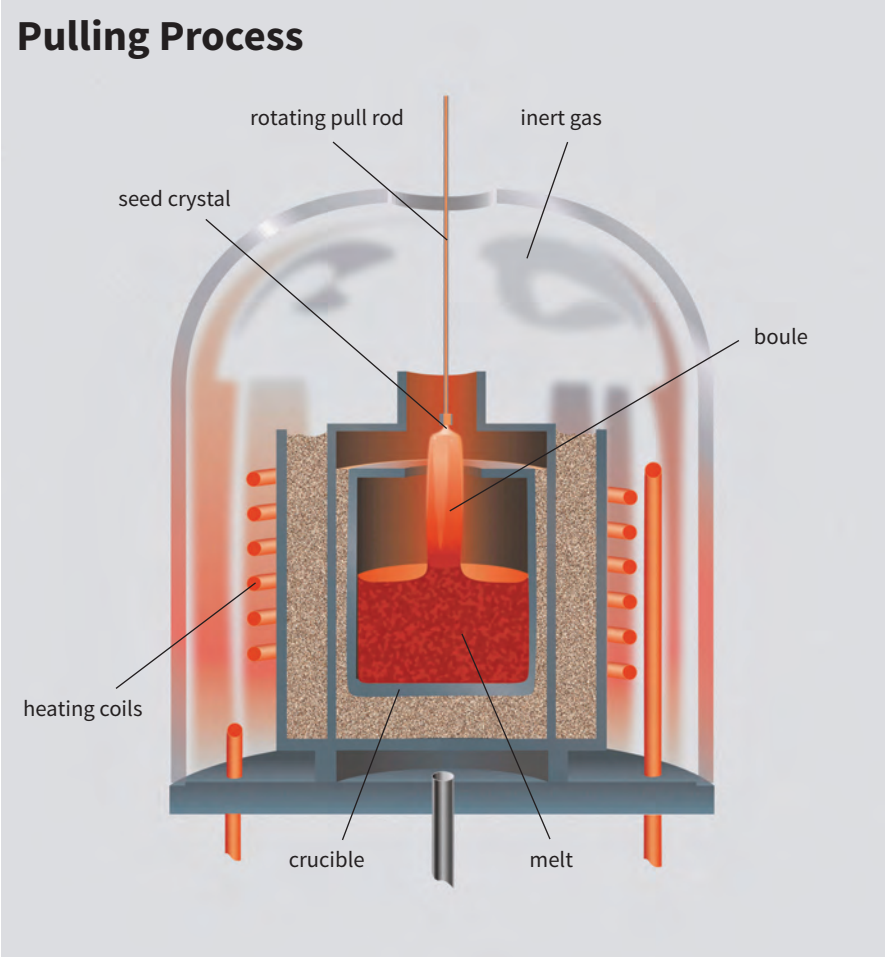
the melt," technique for use in lasers. It's also known as the Czochralski (chuh-KRAWL-skee) method, after its inventor. It was first used to grow synthetic sapphire in 1918.

The Czochralski method permitted the growth of extremely pure titanium sapphire (Ti-sapphire) crystals for laser use. Their ability to produce extremely high-energy and ultra-short pulses advanced fundamental research and holds promise for exciting breakthrough technologies like nuclear-fusion energy.

Crystal pulling also has an advantage for gem-quality synthetic corundum production because grown crystals are large, generally ranging from 5 to 20 kilograms. This provides large quantities of highly uniform rough for faceting. Pulled synthetic sapphire grows over periods of days to weeks. It has uniform quality and color but might exhibit color banding and round bubbles.

Pulling begins with the melting of powdered ingredients in a crucible (a container that can withstand high heat). A tiny *seed crystal*—used to initiate and provide a framework for synthetic growth—is attached to a rod that touches the melt's surface.

Seed crystal—A tiny crystal used as a template to control the size, speed, or direction of growth and the shape of a growing synthetic crystal.



Peter Johnston/GIA

In the pulling process, the synthetic crystal grows from a seed. The seed is dipped in a chemical melt, then gathers material as it is pulled away.

Bill Varie/Getty Images

The pulling technique was developed to meet the need for inclusion-free synthetic ruby in laser equipment. Pulled crystals can be used for industrial, technological, or jewelry applications.

As the rod rotates and slowly pulls up out of the melt, it pulls some of the melt mixture with it. The melt mixture on the rod cools and crystallizes, forming a cylinder. The cylinder can be up to 10 cm (4 inches) in diameter and more than 40 cm (16 inches) long.

Conditions have to be just right for this process to work. If the temperature is too high, the seed crystal melts. If the temperature is too low, the melt mixture solidifies into a glass-like mass rather than a crystal. And, if the melt crystallizes too fast, the result is a mass of many small crystals rather than a single crystal.

Pulling is more complex and expensive than flame fusion, but it can be faster. Pulled synthetic crystals can form as rapidly as 10 cm (4 inches) per hour. Also, because pulling takes place in a more controlled atmosphere than flame fusion, the resulting synthetics have fewer inclusions. The relative speed of the pulling process and its large, nearly inclusion-free crystals make pulling cost-effective for manufacturers.

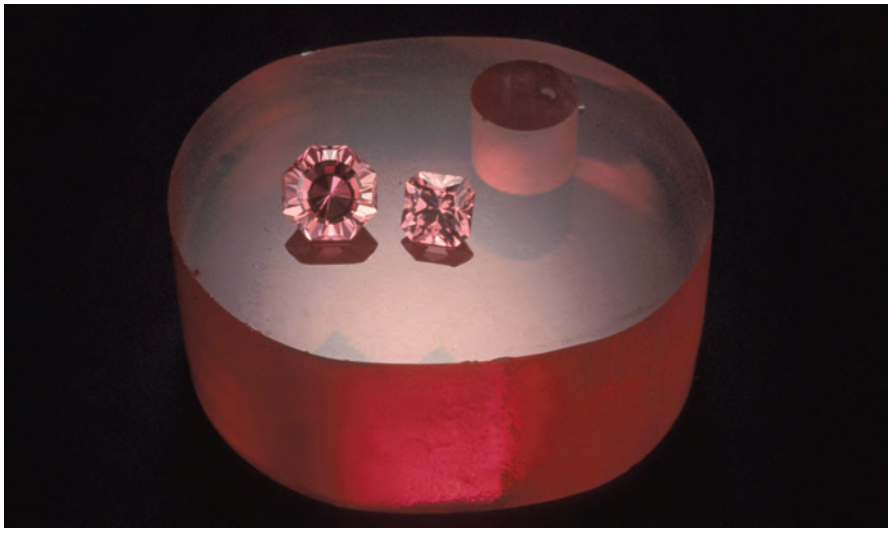
The difference in clarity between flame-fusion and pulled synthetics is noticeable only under a microscope. But the subtle difference is important in industrial applications where synthetic ruby used in lasers must be as free of inclusions as possible.

In the 1960s and 1970s, pure, durable and highly transparent pulled colorless synthetic sapphire was used for many industrial applications, including protective laser coverings for the military and aerospace industries, bulletproof armor, and scratch-resistant surfaces.

Because sapphire is a strong material and doesn't transmit electricity—it's an insulator—it's also suitable for single-crystal semiconductors. This allowed development of faster and more energy-efficient electronic circuitry. The same technology also led to the development of light emitting diodes (LEDs), which are likely to become the next generation of highly efficient and versatile lighting.

KEY CONCEPTS

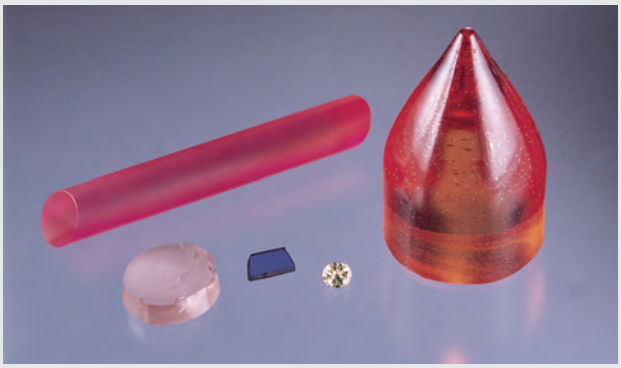
Pulling is important for sapphire synthesis because it produces extremely pure, high-quality crystals for technological and science applications.



Robert Weldon/GIA

These synthetic faceted sapphires and the boule they are resting on were all produced by the pulling method. The boule is a section of the original and weighs 343.33 cts.

Pulled Synthetics



Maha Tannous/GIA

Synthetic crystals grown by the pulling method tend to have rounded outlines and circular cross-sections. Many were originally grown for laser research.

Robert Weldon/GIA

Union Carbide, the giant US industrial firm, used the pulling method to grow synthetic pink sapphires, using titanium rather than chromium as a coloring agent. These stones fluoresce blue under shortwave ultraviolet light, which helps separate them from natural stones.

Robert Weldon/GIA

These rough and faceted synthetic blue sapphires were produced by the Czochralski pulling method.

John Koivula/GIA

The Japanese company Kyocera grew these pulled synthetic star rubies. Today, most synthetic star corundum is grown by the flame-fusion method.

Terri Weimer/GIA

This pulled synthetic colorless corundum slab contains numerous gas bubbles. This means it was probably grown for experimental purposes, as synthetic gem production is usually inclusion-free.

Pulled Synthetics (continued)

Green pulled YAG has been used to imitate both emerald and tsavorite garnet, but it's a much more effective imitation of the latter.

Maha Tannous/GIA

The synthetic alexandrite variety of chrysoberyl is also grown by the pulling method. This stone, grown in the early 1990s, weighs 1.26 cts. Gemological examination revealed distinct curved growth features.

Terri Weimer/GIA

GGG is produced by the pulling process, resulting in cylindrical boules. This GGG specimen weighs 447 g (15 oz.), but it's just the top portion of a much larger boule.

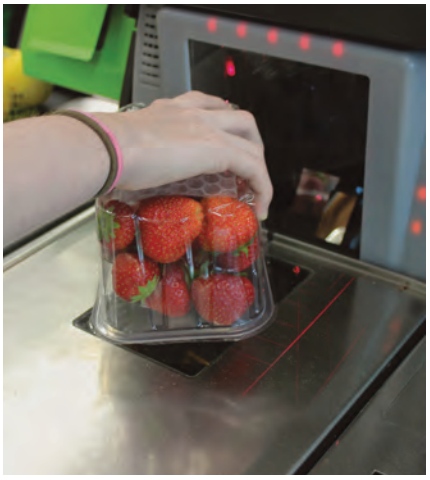
Terri Weimer/GIA

Cylindrical boules of YAG might be produced by the crystal pulling process. This pulled green YAG boule, manufactured by Linde, dates from 1967.

Consumer applications of synthetic white sapphire eventually followed. Synthetic sapphire's scratch resistance made it a good replacement—starting in the late 1970s—for the glass "window" on supermarket barcode readers. The top layer of the scanner window is made of a very thin slice of sapphire, which keeps the glass under it scratch-free and less likely to sustain damage from hard objects like cans.

Watchmakers also prefer it to glass as a scratch-resistant cover for watch faces and the touchscreens on high-end smartwatches. Synthetic sapphire windows can also be used to protect biometric fingerprint sensors, as well as for cellphone camera lenses.

Besides corundum, gems synthesized by pulling include synthetic alexandrite and cat's-eye alexandrite and green chrysoberyl. The pulling method also produced YAG (yttrium aluminum garnet) and GGG (gadolinium gallium garnet), two manmade crystals that once served as diamond imitations.



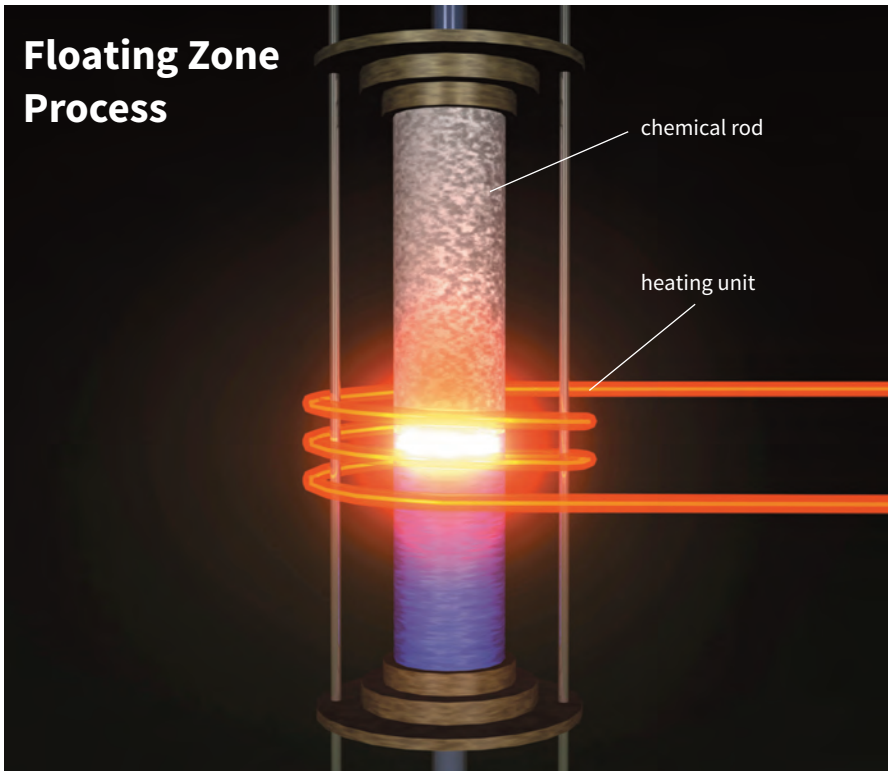
iStockphoto

Pulled colorless synthetic corundum is used as a "window" in supermarket barcode readers because it's much more durable than glass.

Floating Zone

Scientists first developed the *floating zone* crystal growth method in 1953, responding to a need for high-quality silicon semiconductors. The process starts with a mixture of the components necessary to make up the desired synthetic crystal. Instead of a powder, however, the mixture is merged together (sintered) into a rod-shaped solid. As the rod rotates, a heating unit passes over it. This causes the material in the rod to crystallize in "zones." Eventually, this transforms the rod into a single crystal.

Floating zone —A melt process where a heating unit passes over a rotating solid rod of chemicals until it forms a synthetic crystal.



Peter Johnston/GIA

In the floating zone process, a heating unit passes over a rotating solid rod of chemicals until it crystallizes into a single synthetic crystal.

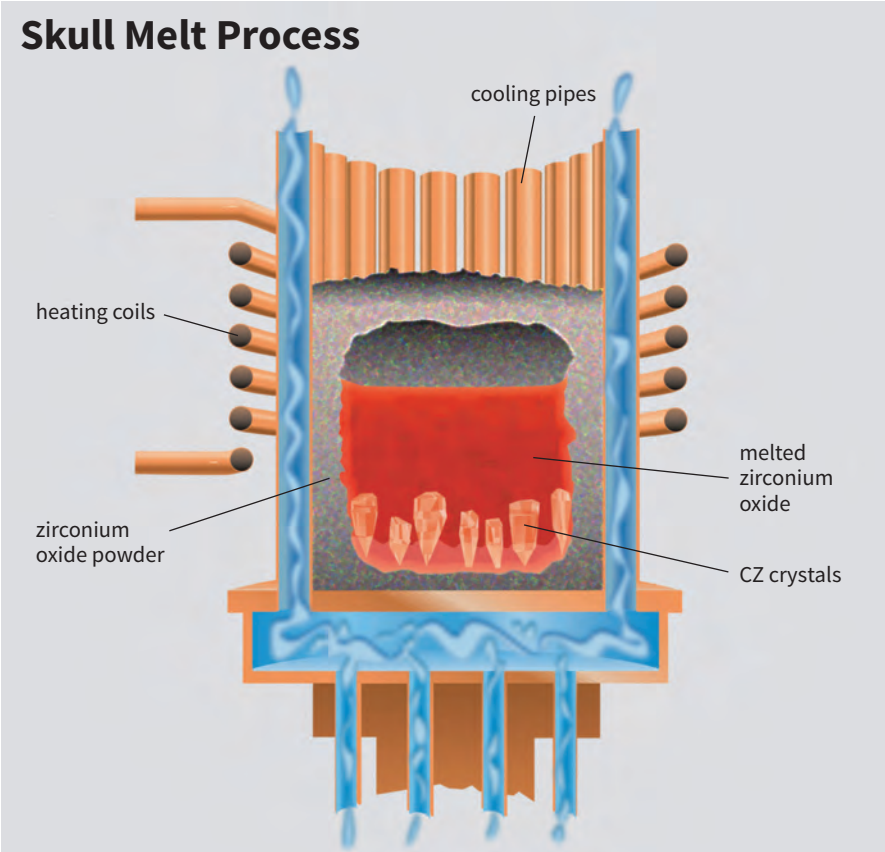
In the 1980s, the Seiko company created synthetic ruby, sapphire, and chrysoberyl by the floating zone method. Seiko used the process to develop a better watch crystal, and briefly marketed faceted synthetics like these in a line of jewelry.

In the 1980s, a Japanese company, Seiko, used the floating zone method while attempting to make a better watch crystal. The company's experiments resulted in the manufacture of synthetic corundum. They were already producing synthetic alexandrite chrysoberyl. For a time, they sold their synthetics in a line of jewelry, but the company no longer makes synthetics for gem use.

The floating zone method can produce very pure material because it takes place within a vacuum or inert gas, eliminating potential contact with contaminants. Impurities in the seed material migrate to the end of the liquid melt zone. Advances and modifications to this method allow the manufacturing of rods up to 150 mm in length. As with other high-purity synthetics, the material is used primarily in semiconductors and for other industrial applications.

Skull Melt

Scientific research took diamond imitations to a new level with the introduction of synthetic cubic zirconia (CZ). In 1937, two German mineralogists discovered small crystals in natural zircon that proved to be the cubic form of zirconium oxide (zirconia). They learned that it had a very high melting point, so they created synthetic CZ for use in manufacturing chemical-resistant industrial ceramics.



Peter Johnston/GIA

The skull melt process is a synthetic-crystal growth method that uses cooling pipes that surround melted chemical ingredients. Colorless and colored CZ is made by this process.

Tino Hammid/GIA

These CZ boules demonstrate the synthetic gem's variety of colors.

Shane McClure/GIA

Black CZ was introduced in the early 1990s in response to a rise in the popularity of black diamonds. The finished stone weighs 6.60 cts., the rough piece weighs 65.09 cts.

Nicholas DelRe/GIA

A synthetic gem material might turn up where you least expect it. This 64.19-ct. Buddha sculpture was carved from yellow CZ.

The special high-temperature technique that produces CZ is called the *skull melt* process. The term "skull" refers to a shell of water-cooled copper pipes circling the zirconium oxide powder. The pipes keep the outer layer of powder cool. Heat from radio frequency coils melts the inner material, which crystallizes. Growers create colors with various additives.

Skull melt—A synthetic-crystal growth method that uses cooling pipes around an interior of melted chemical ingredients.

Shane McClure/GIA

CZ is a relatively inexpensive synthetic that comes in a wide range of colors. Colorless and colored CZ can imitate diamonds and colored stones.

The high melting point that made it desirable for industry also made CZ a challenge to grow in crystals big enough for faceting. Russian researchers came up with a practical way to grow large CZ crystals in 1972. Four years later, CZ poured into the jewelry market. It immediately became a best-selling diamond imitation. One reason for its popularity is that colorless CZ is inexpensive: It can sell for pennies a carat in large wholesale quantities.

In its colored varieties, ranging from pastels to vivid shades, CZ offers a fashionable alternative to costly colored diamonds.

Synthetic Cubic Zirconia

Alan Jobbins

Manufacturers grow synthetic CZ in a variety of attractive colors using the skull melt process.

Terri Weimer/GIA

As demand grew for CZ as a material in its own right, manufacturers started to produce a wider range of colors including aquamarine greens and blues, peach, tanzanite blue, and dark pink.

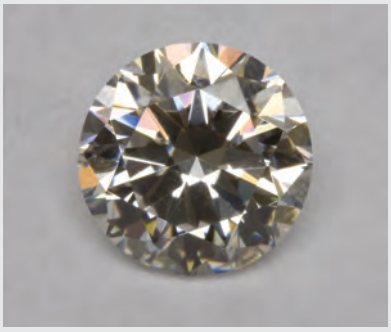
Eric Welch/GIA

In the early 2000s, translucent-to-opaque CZ colors, called “opaline,” made their debut in the marketplace.

Eric Welch/GIA

Manufacturers can produce CZ with an opaque metallic appearance that imitates marcasite or pyrite. It has synthetic CZ’s typical columnar structure.

Synthetic Cubic Zirconia (continued)



Valerie Power/GIA

Millions of round brilliant CZs are manufactured to meet the demand for low-priced accent stones and to imitate diamond solitaires in low-cost jewelry.

Valerie Power/GIA

Valerie Power/GIA

There's a color-change CZ that shows a distinct shift from yellowish green under fluorescent light (left) to reddish brown under incandescent light (right).

Valerie Power/GIA

CZ is often used to create diamond replicas. Many prestigious jewelers put CZ replicas in their window displays, where the presence of natural diamonds might be an insurance risk.

Tino Hammid/GIA

The most important use of CZ is still as a diamond imitation. Colored and fancy-cut CZs can be extremely effective imitations.

Valerie Power/GIA

The skull melt process allows the growth of very large CZ crystals, so large fashioned gems like this 670.35-ct. giant are not uncommon.

Valerie Power/GIA

With the explosion of interest in black diamonds, it was inevitable that manufacturers would produce a lower-cost CZ alternative. This example weighs 21.49 cts.

Valerie Power/GIA

Even in smaller sizes, CZ is an extremely effective diamond simulant. Black and colorless CZ melee grace this white-metal heart pendant.

Solution Processes

Solution processes make up the second major category of gem synthesizing methods. One way that solution processes are different from melt processes is that the ingredients used in solution processes don't necessarily match the composition of the crystals being made. The result is that a solution-process crystal is different in composition from its initial ingredients.

Solution processes tend to be slower and more expensive than melt processes, but manufacturers have found them useful for two reasons. First, the gems synthesized using solution processes resemble natural gems very closely.

Synthetic gems produced by some solution processes display growth patterns similar to those of natural gems. The similarity inspires many manufacturers to promote their solution-process synthetics as more natural looking—even under magnification—than melt-process synthetics.

The second reason solution processes are useful is that some desirable gem materials simply can't be manufactured through melt processes—at least not in gem quality.

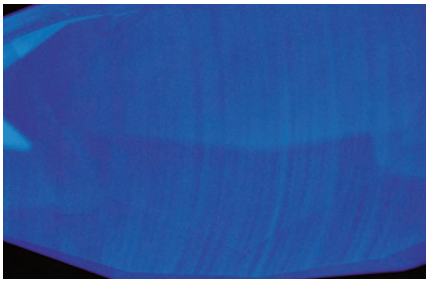
Quartz and emerald are two such materials, and each poses a different problem. When the chemical components of quartz are subjected to a melt technique, they don't crystallize when they cool. Instead, they combine into a thick, semi-fluid glass. And emerald's chemical components appear to melt at different temperatures. Instead of solidifying into the desired beryl crystals during the melt process, the separate ingredients cool at separate rates into three distinct materials—phenakite, chrysoberyl, and quartz. Fortunately, solution processes offer alternatives for quartz and emerald growers.

In general, solution methods fall into the high cost, low volume category. There are two common solution processes for synthesizing colored gems: *flux* and *hydrothermal*.

Production of flux-grown and hydrothermal synthetics takes months—even as long as a year—but they exhibit uniform color distribution, less strain, and more natural-looking inclusions than melt-process synthetics. The market for solution-grown corundum is much smaller than that for flame-fusion material.

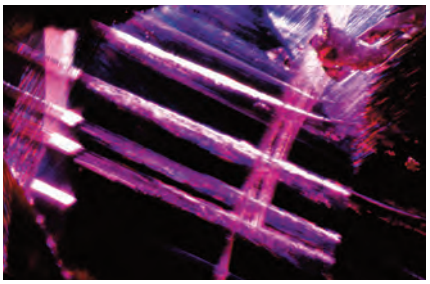
Flux Growth

Thousands of years ago, Roman scholar Pliny the Elder praised emerald for nourishing but never dulling the senses. But it wasn't until the 1930s that scientists finally synthesized a commercially profitable version of the desirable, deep green gem. In that decade, a US college student named Carroll Chatham began marketing his flux-grown emerald, the result of pioneering experiments he'd begun while still a teenager living at home.



Shane Elen/GIA

Melt-process synthetics, like this flame-fusion synthetic sapphire (6X), can show curved growth patterns unlike any found in nature.



John Koivula/GIA

Solution-process synthetics, like this flux-grown synthetic ruby (10X), have more natural-looking straight and angular internal patterns.

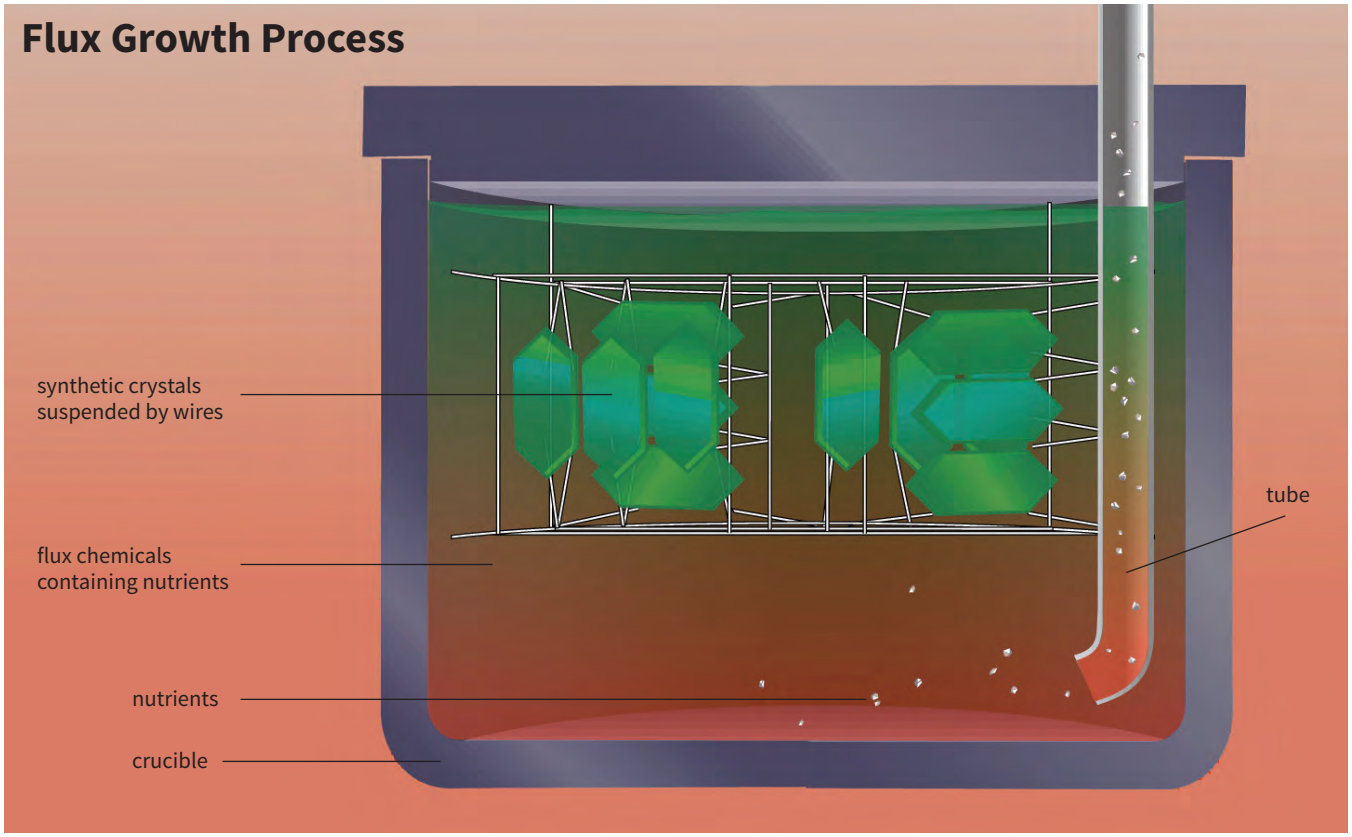
Flux growth—A process in which nutrients dissolve in heated chemicals and then cool to form lab-grown crystals.

Hydrothermal growth—A process in which nutrients dissolve in a water solution at high temperature and pressure and then cool to form lab-grown crystals.

KEY CONCEPTS

Solution processes are generally slower and more expensive than melt processes.

Solution processes can synthesize gems that closely resemble natural gems.

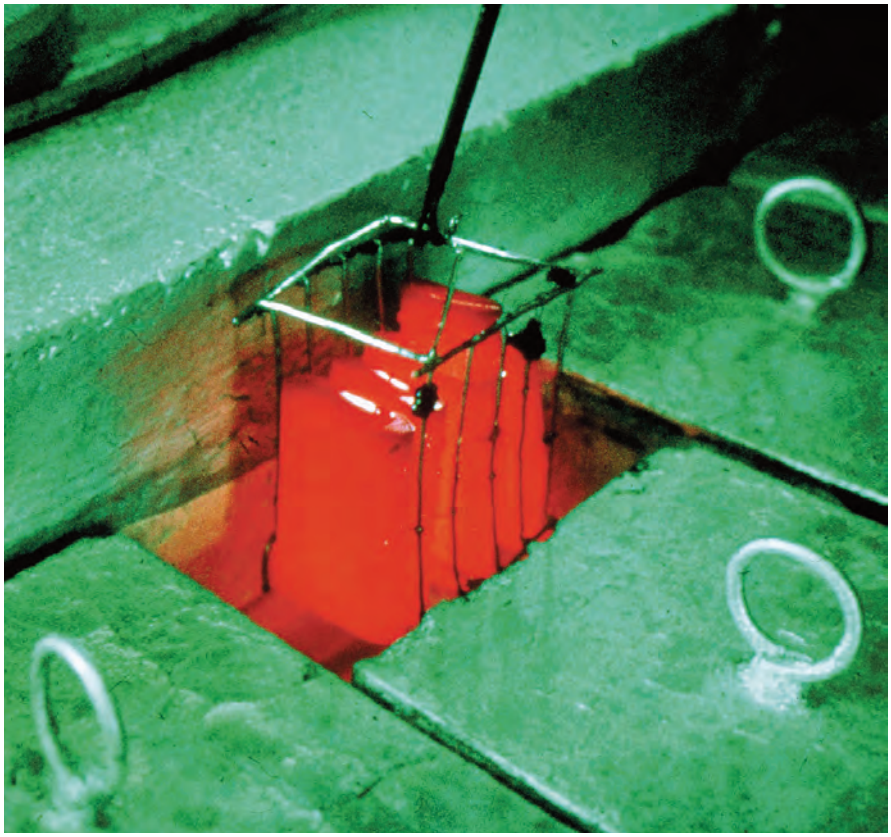


Peter Johnston/GIA

In the flux process, nutrients dissolve in heated chemicals, then cool and crystallize to form synthetic crystals. The entire process can take up to a year. The tube lets crystal growers add nutrients in a controlled manner.

Tino Hammid

The growth of synthetic emerald takes a great deal of time and money, but the results are worth it. Flux-grown synthetic emerald is shown here in 1.32-ct. fashioned and 1.42-ct. rough forms.



Alan Jobbins

After nine months of growth, several red-hot synthetic emeralds are removed from the furnace. The equipment used in the flux process must withstand extremely high heat.

Carroll Chatham began marketing his flux-grown synthetic emerald in the late 1930s.

Today, emerald is not the only flux-grown gem. Others include synthetic rubies, sapphires, alexandrites, and spinels. In addition to growing emerald, Chatham refined the corundum flux-growth process in the mid-twentieth century and began marketing gem-quality synthetic ruby in 1959 and synthetic blue sapphire in 1975. Growing a synthetic gem by the flux method takes time and money. Crystal growth can take up to a year, and the equipment is very expensive. But the results, especially when it comes to emerald, are well worth the effort.

The flux process requires a crucible that resists corrosion and can withstand high temperatures. Platinum crucibles are best, but gold, silver, or iron containers also work. The crystal grower heats the crucible and combines the powdered ingredients inside it with flux. Flux is a solid material that, when melted, dissolves other materials in the same way that water dissolves sugar. As the dissolved chemical solution gradually cools, synthetic crystals form, ranging from about 0.5 cm to 7.5 cm (0.25 inch to 3 inches) in diameter.

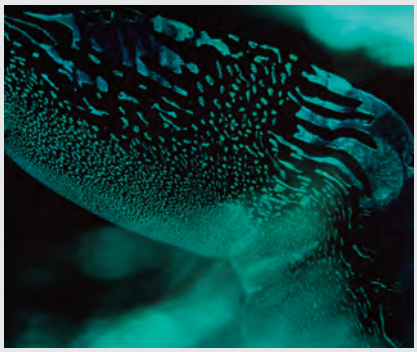
A seed crystal usually initiates the growth process. However, growers have succeeded in creating a flux-grown synthetic ruby without using a seed crystal as a foundation. The process they developed is called *spontaneous nucleation*.

Spontaneous nucleation—A synthetic-crystal growth method that starts without a seed crystal.

Flux-grown Synthetics

Terri Weimer/GIA

Although the synthetic emeralds in this 237.94-ct. cluster of Chatham flux-grown crystals look very natural, their vivid color and inclusions mark them as synthetics.



Fingerprint-like inclusions made up of flux droplets are characteristic of synthetic emerald grown by this method. Gemologists call them wispy veils.

Kurt Nassau

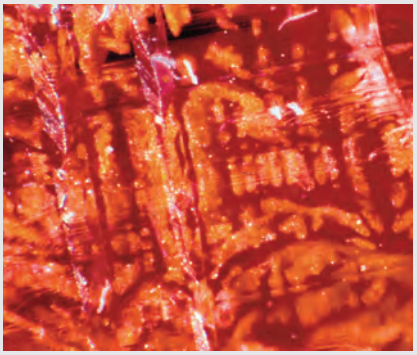
Along with developing the flame-fusion process, Verneuil also experimented with flux growth. These samples of that experimental work are from the collections of the Smithsonian and the Paris Museum of Natural History.

Eric Welch/GIA

Unlike flame-fusion rubies, flux-grown rubies have complex geometric crystal shapes similar to natural gems. This Ramaura synthetic ruby displays complex twinning and flattened tabular form.

Eric Welch/GIA

These intergrown Ramaura synthetic rubies show clear hexagonal crystal growth markings on their surfaces. The flattened tabular form is typical.

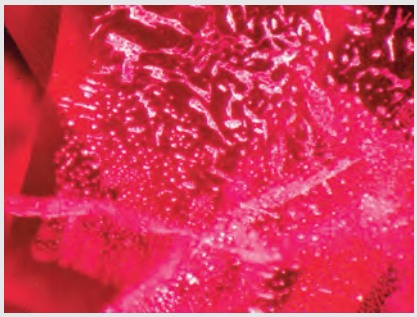


Alan Jobbins & Duncan Pay

When present, the flux in a Ramaura synthetic ruby has a very distinctive orange-yellow color, with high relief and a crackled or crazed texture.

Alan Jobbins

Unlike in Ramaura products, the flux in Kashan synthetic rubies is white. It often forms strings of droplets that gemologists call “rain.”



John Koivula/GIA

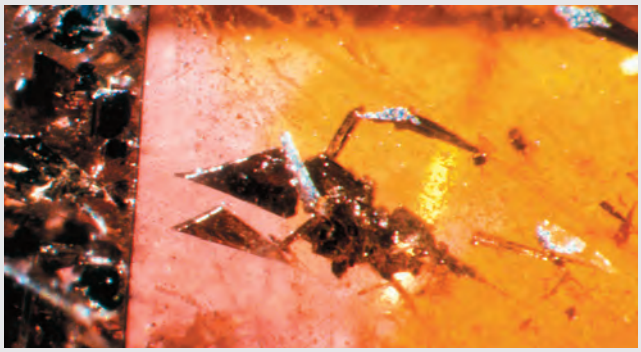
This flux fingerprint in a Kashan synthetic ruby shows the typical high relief of the flux, its texture, and its “drippy” appearance.

Maha Tannous/GIA

Flux-grown synthetic gems can be quite large. This fancy pink Chatham synthetic sapphire weighs 884 cts.

Eric Welch/GIA

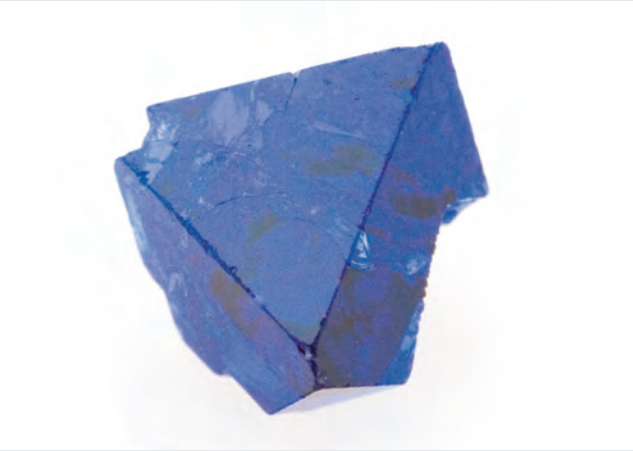
This Chatham flux-grown synthetic sapphire bears the characteristic signs of its growth process: many highly visible platinum platelets from the crucible it grew in.



Alan Jobbins & Duncan Pay

A close-up of the same stone reveals the reflective, metallic nature and triangular shape of the platinum platelets.

Like Ramaura rubies, Douros synthetic rubies grow from spontaneous nucleation, without seed crystals. The 44.74-ct. crystal and the finished stones surrounding it represent the best quality from this manufacturer.



This Russian flux-grown synthetic blue spinel has the same arrangement of triangular faces as a natural crystal. Its broken base signals its synthetic nature, as the points on most natural gem-quality spinel crystals are intact.

Jessica Arditi/GIA

Flame-fusion synthetic rubies are sometimes treated by creating fractures and then heating them in a flux. This results in features similar to flux-grown synthetic rubies or even some heat-treated natural rubies.

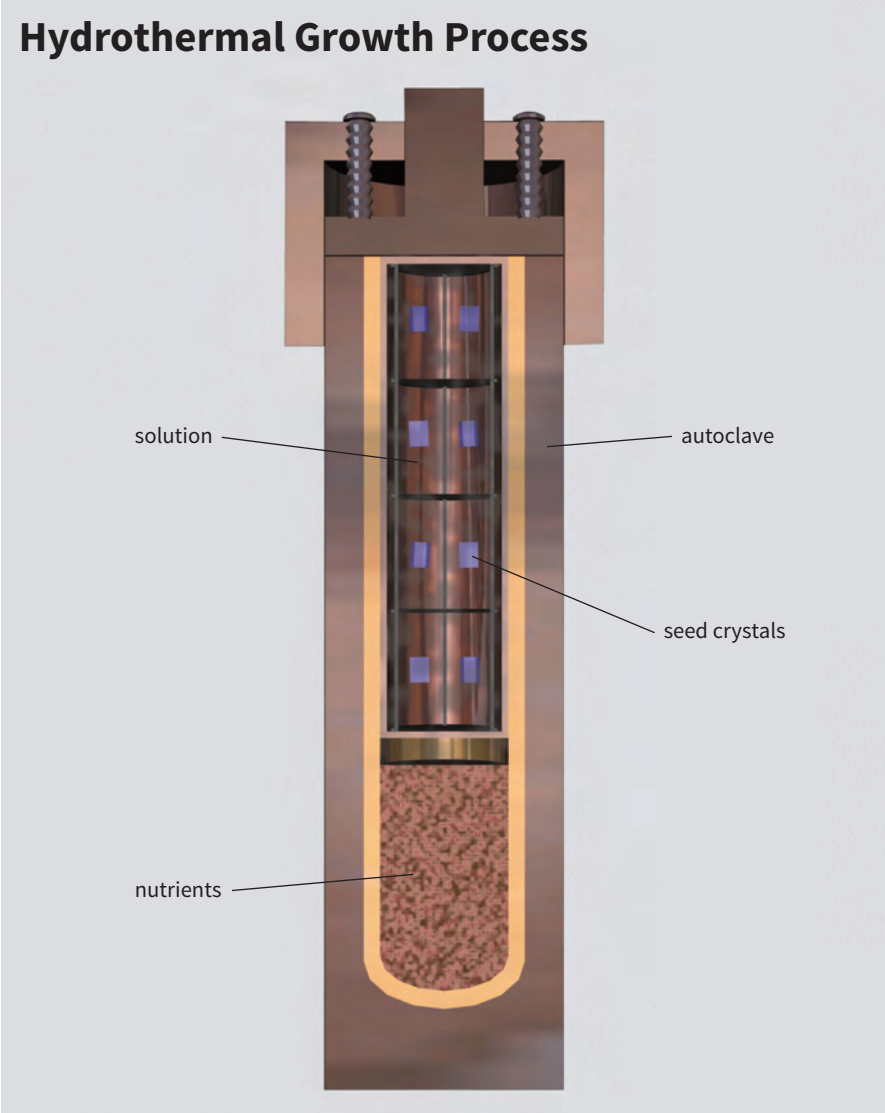
Eric Welch/GIA

Alexandrite chrysoberyl can be synthesized using the flux method. Like emerald, alexandrite contains beryllium, which is toxic and requires very special precautions during growth. Few manufacturers have the facilities or desire to cope with beryllium containment today.

Hydrothermal Growth

Like the flux process, the hydrothermal growth process is slow and expensive. But it's the only method for successfully growing synthetic quartz.

The hydrothermal process requires heat and pressure and imitates the conditions deep in the earth that result in the formation of natural gems. The hydrothermal process uses a steel container called an autoclave, which is similar to a pressure cooker. Crushed chemical compounds fill the bottom of the autoclave. Synthetic quartz seed crystals (also made from a hydrothermal process) or natural quartz seed crystals are suspended within it. The autoclave also contains pressurized, high-temperature water.



Peter Johnston/GIA

In the hydrothermal process, nutrients dissolve in a solution of water and chemicals at high temperature and pressure. As the solution rises to the top, it cools and gathers new material, forming synthetic gem crystals.

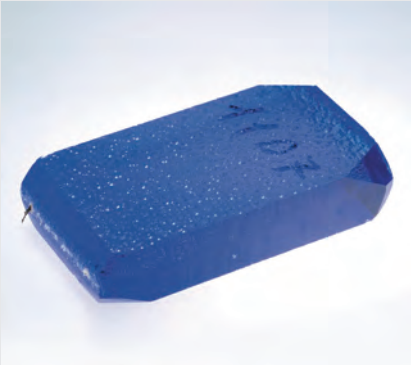
As the chemicals at the bottom dissolve in the water, they form a solution that rises to the top, where it's cooler. As this happens, seed crystals gather the new material, and large gem crystals form. Hydrothermal quartz crystals can measure up to 46 cm (18 inches) long and 15 cm (6 inches) in diameter.

Gem-quality quartz, such as rose quartz, citrine, and amethyst, is attractive. But natural gem-quality quartz is plentiful, and it retails for far less than rarer gems like emerald, ruby, and sapphire. So scarcity is not the reason that researchers went to the trouble of developing and implementing a way to synthesize gem-quality quartz.

Yoav Levy/PictureQuest

The hydrothermal process involves high temperatures and pressures that imitate the earth's natural conditions. These synthetic quartz seed plates are used to initiate crystal growth.

Hydrothermal Synthetics

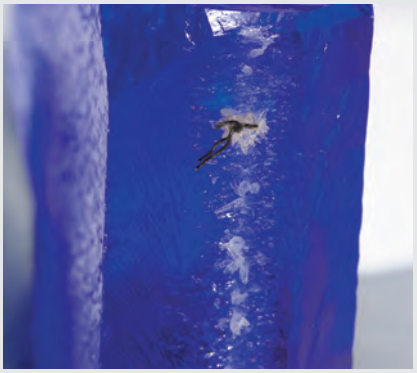


Terri Weimer/GIA

Vivid blue color and tabular shape identify this 1,107-kg (39-oz.) crystal as hydrothermal synthetic quartz.

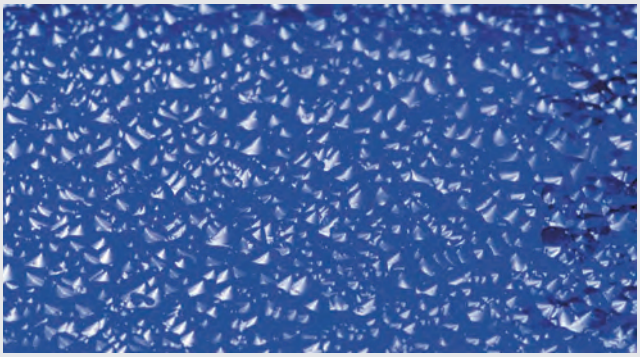
Terri Weimer/GIA

Viewing this hydrothermal synthetic blue quartz crystal from a certain angle makes its colorless seed plate readily visible.



Terri Weimer/GIA

A top view of the same hydrothermal synthetic quartz crystal shows the remains of the wires that held it in the autoclave during growth.



Terri Weimer/GIA

A close-up of the surface of a hydrothermal synthetic blue quartz crystal reveals a distinctive and characteristic cobbled texture.

Eric Welch/GIA

Cobalt is the coloring agent in dark blue hydrothermal synthetic quartz. Fashioned hydrothermal synthetic blue quartz is unlike any naturally occurring quartz variety in appearance.

Eric Welch/GIA

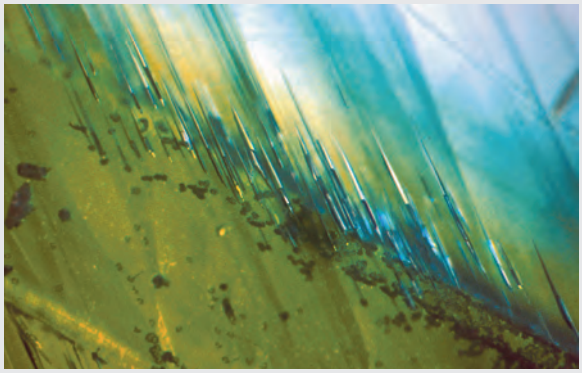
Much of the hydrothermal synthetic quartz seen in the trade is grown in Russian labs. This Russian hydrothermal amethyst weighs 133.2 g (4.7 oz).

Eric Welch/GIA

Hydrothermal synthetic emerald from Russia and China has largely replaced flux-grown synthetic emerald in the market. The colorless seed plate is clearly visible in this Russian specimen.

Eric Welch/GIA

This Russian-grown synthetic emerald's tabular shape and cobbled surface texture readily identify it as a product of hydrothermal growth.

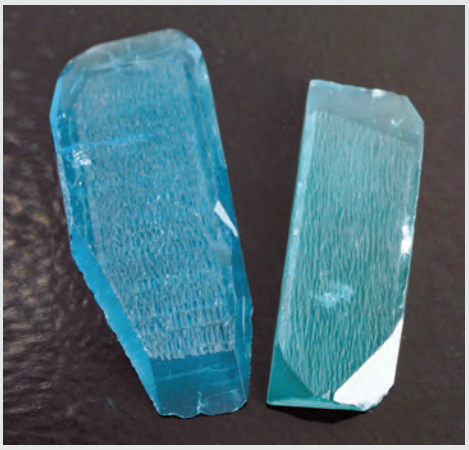


John Koivula/GIA

These inclusions, called nailhead spicules, are characteristic of hydrothermal synthetic emerald. They're often densely arranged near the crystal's seed plate. This synthetic emerald was manufactured in China.

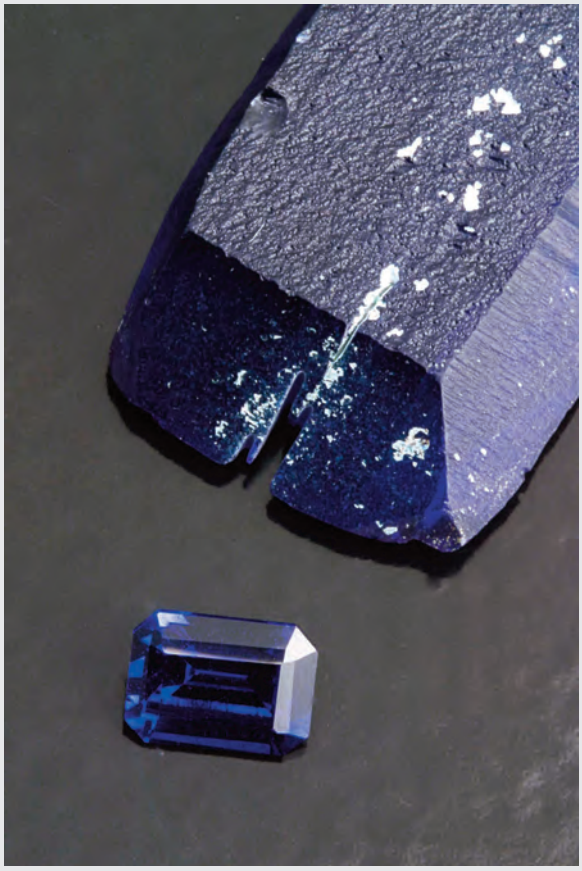
Terri Weimer/GIA

Like their natural counterparts, hydrothermal synthetic rubies are colored by trace amounts of chromium.



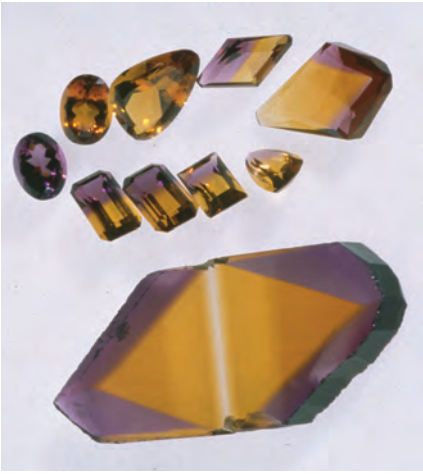
Eric Welch/GIA

The tabular shapes of these hydrothermal synthetic aquamarine crystals separate them from natural stones, which usually grow as six- or twelve-sided columns.



Terri Weimer/GIA

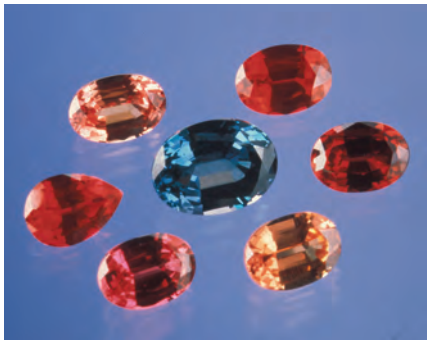
Hydrothermal synthetic blue to violet sapphires owe their color to a combination of nickel and chromium. This can result in pleochroic colors, like reddish violet and blue-green, that are different from those shown by natural blue sapphire.



Maha Tannous/GIA

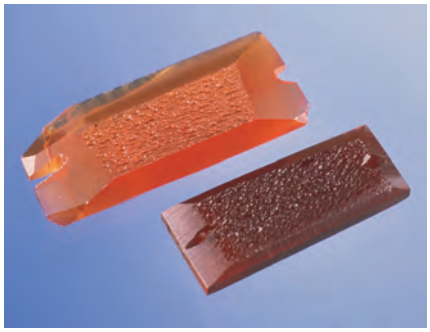
Maha Tannous/GIA

The pink synthetic quartz crystals and faceted gems (above) and the synthetic amethyst, citrine, and ametrine (left) are products of the hydrothermal process. These crystals are typical of the wide variety of synthetic quartz colors offered in the 1990s. The colorless area in the center of the large synthetic ametrine is its seed plate.



Maha Tannous/GIA

These fashioned samples show the broad color range of hydrothermal synthetic corundum. The large blue-green synthetic in the center measures approximately 9x7 mm.



Tino Hammid/GIA

The rough hydrothermal synthetic corundum samples from Russia were grown on tabular seeds. They're very different in shape from natural crystals.

The real reason is that it plays a key role in technology. For one thing, it can generate an electric current when it's placed under pressure. And thinly sliced quartz can vibrate in precise response to alternating current. Scientists put these virtues to practical use in watches, clocks, communications equipment, filters, and oscillators.

Lab-grown amethyst and other synthetic quartz varieties found their way into jewelry as a byproduct of technology. The first hydrothermal quartz appeared in laboratories in the 1890s. It wasn't until World War II that the synthetic was widely available commercially. Today, manufacturers routinely market jewelry set with synthetic amethyst, citrine, and ametrine. This leads many in the jewelry trade to believe that substantial amounts of synthetic amethyst might be misrepresented as natural in the marketplace.

Hydrothermal synthetic emerald for jewelry came on the scene in 1960. Hydrothermal emerald uses a hydrothermal synthetic beryl seed crystal as a base. Finished emerald crystals can be up to 2 inches (5 cm) long, depending on how much time is allowed for crystal growth.

After years of experimenting with different ways of creating hydrothermal ruby and sapphire, researchers succeeded in developing both gems in marketable quality. Since the 1990s, joint ventures between Russian growers and Thai businesses in Bangkok have marketed hydrothermal synthetic corundum, including ruby and blue, yellow, and pink sapphire. Other manufacturers had been having trouble achieving a synthetic blue sapphire with even coloration. Russian growers met this market need by using nickel as a coloring agent during the growing process to get a consistent blue color in their synthetic sapphires.

Retail prices of synthetic gem corundum have been fairly consistent over the past couple of decades, even with increasing demand. Today, there are more producers in regions with lower operating costs. Just as crystal growth techniques vary widely, so do the retail prices of faceted synthetic

Steve Cole/PhotoDisc

Synthetic quartz has special qualities that make it ideal for electronic applications, like quartz movement for watches (left) and quartz light bulbs (right).

Tino Hammid/GIA

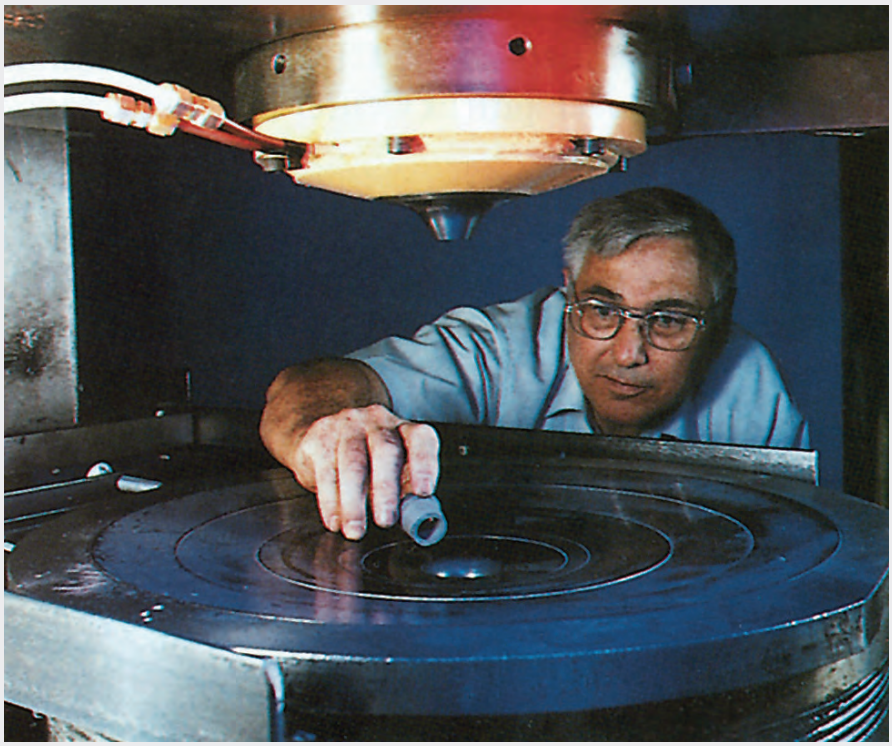
These hydrothermal synthetic emeralds were grown in China. The gold-colored wires on both sides of the 4.72-ct. synthetic rough crystal were used to suspend the seed during the growth process. The fashioned gems range from 0.13 ct. to 0.61 ct.

Robert Weldon/GIA

Quartz varieties, like the synthetic amethyst in this pendant, found their way into jewelry after being developed for industrial applications.

sapphires, which can range from $1 to $1,000 per carat. Most fashioned flame-fusion synthetics retail for less than $5 per carat. Pulled synthetics are about ten times more expensive, and solution-grown material might cost as much as several hundred dollars per carat. For each growth method, rough material costs about one-tenth the price of faceted goods.

Lab-grown Diamond Alternatives



Courtesy General Electric

In the 1970s, researchers at General Electric produced gem-quality synthetic diamond. Here, a GE scientist prepares the high-temperature, high-pressure "belt" apparatus used for growing the synthetic crystals.

Ever-popular diamond is prized in jewelry the world over. The constant demand for earth's hardest gem has inspired continuing attempts to grow a convincing, inexpensive diamond alternative.

Synthetics

Many years of research resulted in the successful production of synthetic diamonds in the 1950s. But those early synthetics were of industrial quality.

In the 1970s, researchers at General Electric used a high-pressure, high-temperature method to produce yellow, blue, and near-colorless gem-quality synthetic diamond crystals. They displayed properties that made them very different from natural diamond, including uneven ultraviolet fluorescence, metallic inclusions, and distinctive growth features.

A number of manufacturers produced synthetic gem-quality diamond crystals for industrial use during the 1980s. In 1997, manufacturers in Russia and the Ukraine introduced colorless to near-colorless synthetic diamonds that resembled natural diamonds more closely than any earlier versions.

In 2003, Apollo Diamond Inc. produced gem-quality synthetics using chemical vapor deposition (CVD) technology. It uses a chemical process where carbon deposits form the diamond. This method made the production of colorless to near-colorless synthetic diamonds easier and more cost effective than HPHT processes.

Today, a number of companies produce gem-quality synthetic diamonds in commercial quantities and a broad range of colors, including colorless.

Imitations

Successful diamond imitations can be manmade versions of other materials. You learned about a few of them—synthetic rutile, YAG, GGG, and CZ—in this assignment. There have been many more, including a substance called synthetic moissanite, which appeared on the market as the twentieth century came to a close. It's made by a process called sublimation. Growers vaporize silicon carbide and allow it to re-crystallize on a seed crystal.

Scientists have yet to come up with an alternative that matches the flashing brilliance, lively sparkle, and colorful fire of the legendary natural gem. Manufacturers in China have been successful at producing increasing quantities of small round synthetic diamonds—in the 2-3 mm range—for use in jewelry. But unless manufacturers can reliably produce fine-quality lab-grown diamond for a consistently low price, diamond alternatives will remain a part of the market.

If you want to learn more about synthetic diamonds and diamond imitations, they're covered in greater detail in the *Diamonds & Diamond Grading* course.

Robert Weldon/GIA, courtesy Bostonian Jewelers, Boston

This 14K white gold pendant and platinum ring feature pink and colorless CVD synthetic diamonds. The total weight of the synthetic diamonds is 1.03 cts. for the pendant and 1.08 cts. for the ring.

Maha Tannous/GIA

This 14K gold ring is channel-set with synthetic moissanite. In addition to functioning as a diamond imitation, moissanite is also marketed on its own as a desirable gem.

Lab-grown Diamond Imitations

Tino Hammid/GIA

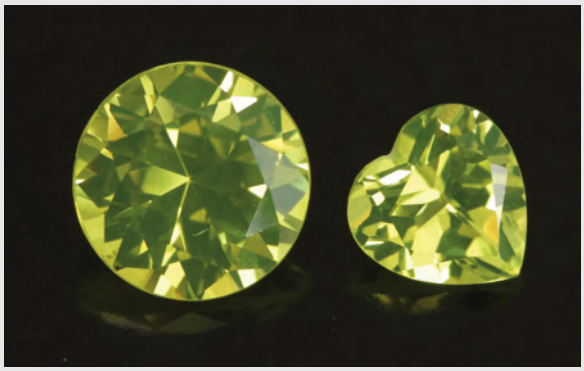
Strontium titanate was developed as a diamond imitation in the 1950s. It was fairly attractive, but it wasn't very durable for jewelry use.

Eric Welch/GIA

Colorless cubic zirconia might be the most convincing diamond imitation. However, its luster, high specific gravity, and strong fire can help to separate it from diamond.

Tino Hammid/GIA

Synthetic rutile's extreme fire, yellowish bodycolor, and strong double refraction help separate it from diamond.



Terri Weimer/GIA

Growers produced YAG in a range of hues to imitate fancy-color diamonds and also fashioned it in a variety of fancy shapes.

GIA & Tino Hammid

YAG has relatively good hardness and brilliance, but its fire is nowhere near the same as diamond's fire.

GIA & Tino Hammid

Because its moderate fire matches diamond's, GGG can be a very convincing diamond imitation, but GGG stones often have a slight brownish tint.

Other Synthetic Processes

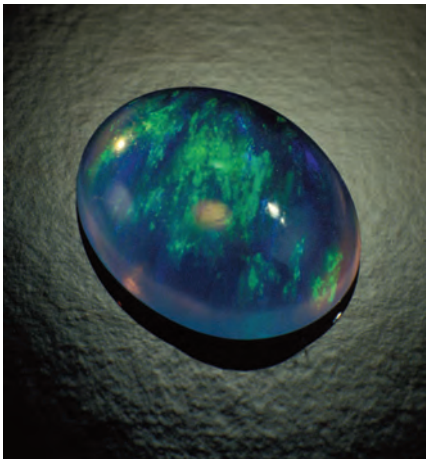
Opal, turquoise, and lapis are very popular gems that aren't always plentiful enough to be affordable for everyone. But their structure and chemical makeup is so unique that they required the development of manufacturing processes all their own.

Synthetic Opal's Three-step Process

Opal is one of the few amorphous gems. This means it lacks a regular crystal structure, but it doesn't mean its beauty is without pattern. The rainbow colors in many opals are the result of a regular arrangement of uniform spheres of silica. Their precise arrangement is a rare occurrence even in nature.

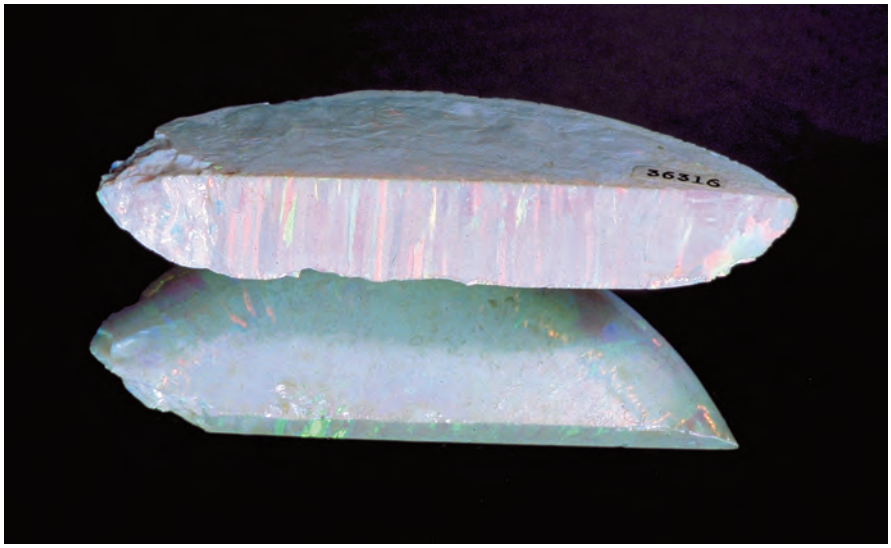
In the 1970s, the Gilson company achieved a believable synthetic opal by combining three steps. The first step uses a chemical process called precipitation to produce microscopic silica spheres of identical size. Next, the spheres "settle" in acidic water for more than a year. Finally, water in a hydrostatic press compresses the material. This forces the silica spheres to consolidate without distorting the stacked arrangement needed for opal's play-of-color.

During the settling phase of the three-step formation process, the synthetic material's structure becomes more compact and loses volume. The volume loss causes cracks that look like mud cracks in a dried-out lakebed. Adding more silica or a polymer binding agent near the end of the process helps to fill in the cracks. When the cracks are filled, it causes a structural pattern that resembles honeycomb or snakeskin. Gemologists look for this pattern as a characteristic of synthetic opal.



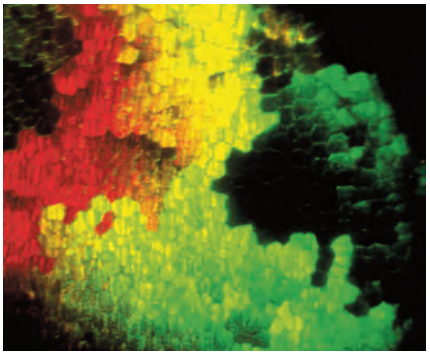
Robert Weldon/GIA

This attractive synthetic opal was made using a three-step process developed by the Gilson company in the 1970s. The process allowed silica spheres to consolidate without distorting the stacked arrangement needed for good play-of-color.



Alan Jobbins

This slice of Gilson synthetic white opal shows a characteristic known as columnar structure. The play-of-color looks like columns on the exposed surface, extending from bottom to top.



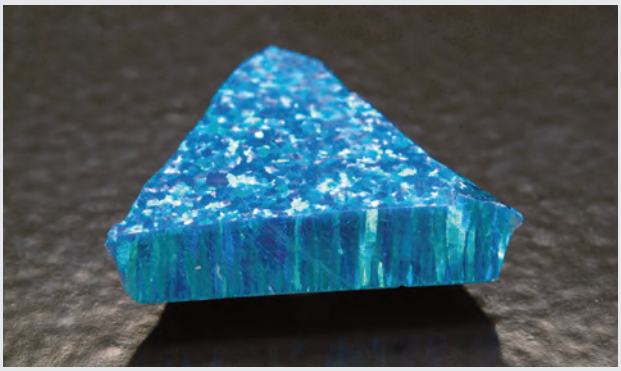
William Videto/GIA

These microphotographs of synthetic opal show the characteristic pattern known as "snakeskin" or "honeycomb." This pattern is a key characteristic of synthetic opal.

Synthetic Opal

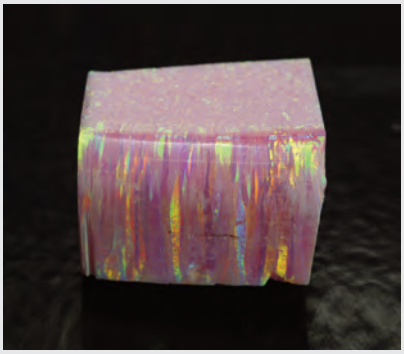
Eric Welch/GIA

Manufacturers produce synthetic opal in a range of bodycolors. Often, they impregnate the material with polymers to make it more stable and durable.



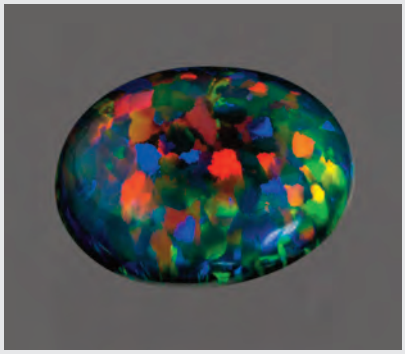
Terri Weimer/GIA

This synthetic polymer-impregnated opal shows the material's characteristic columnar structure.



Terri Weimer/GIA

Growers produce some synthetic opal with unnatural-looking bodycolors. The combination of pink bodycolor and columnar play-of-color make this specimen easy to separate from natural opal.

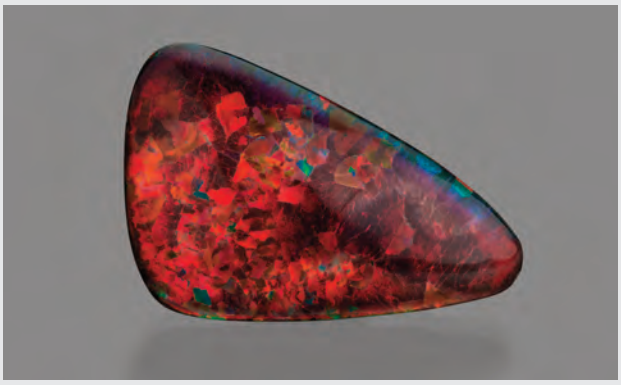


Orasa Weldon/GIA

This 7.25-ct. Gilson synthetic opal cabochon shows the full play-of-color range from red through violet.

Robert Weldon/GIA, courtesy Cody Opal

This Gilson synthetic rough black opal displays columnar structure and strong play-of-color.



Robert Weldon/GIA

Like natural opal, Gilson synthetic opal can be cut into thin slices for use in doublets or triplets.

G. Choudhary/Gem Testing Lab, Jaipur, India

These samples of a synthetic fire opal called "Mexifire" range in size from 3.40 to 4.40 cts. They're grown from a silica gel in a process different from other synthetic opal processes.

Ceramic Processes

You've probably heard the term "ceramic" applied to clay pottery. In general, a ceramic can be any product made from a nonmetallic mineral by firing at high temperature. Two popular non-faceted gems, synthetic turquoise and imitation lapis lazuli, are produced by *ceramic processes*. During the ceramic process, a finely ground powder is heated and sometimes placed under pressure to produce a fine-grained solid material.

Ceramic process—A process in which finely ground powder is heated, sometimes under pressure, to produce a fine-grained solid material.

The cool blues and greens of turquoise have attracted people for centuries. Egyptian royalty wore turquoise as early as 5500 BC, and Native American tribes of the southwestern US once used the gem as a medium of exchange. The familiar gem is a microcrystalline aggregate of copper and aluminum that often features attractive, vein-like inclusions of host rock known as matrix.

Dark blue lapis, treasured by ancient civilizations, has been mined in Afghanistan for more than 6,000 years. The gem is an aggregate of several different minerals. It sometimes contains gold-colored flecks of pyrite that can enhance its appeal.

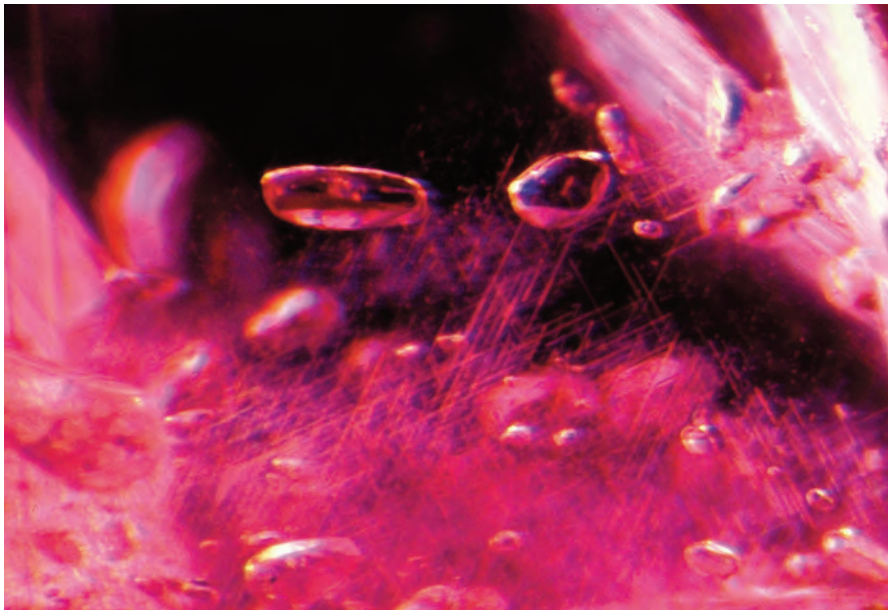
In the early 1970s, Gilson introduced a synthetic turquoise as well as an imitation lapis. (Gilson's lapis is more accurately considered an imitation because it has some ingredients and physical properties that are different from natural lapis.) Although the method for producing these aggregates is not public knowledge, they seem to have been manufactured by some kind of ceramic process.

Robert Weldon/GIA

Gilson imitation lapis lazuli contains ingredients not found in natural lapis, so it's considered an imitation rather than a synthetic. The tablet and cabochons are believed to be made by a ceramic process.

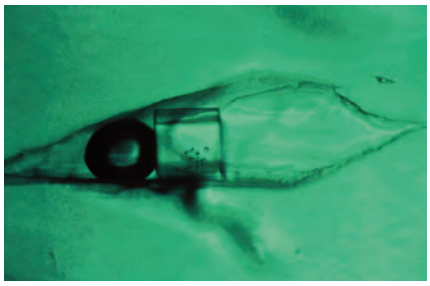
KEY CONCEPTS

Internal and external characteristics can help trained observers separate natural from synthetic gems.



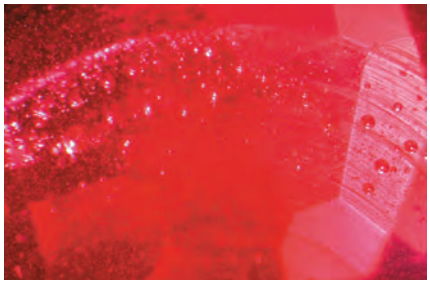
Alan Jobbins

Natural gems often contain microscopic features that are different from those found in synthetic gems. This natural ruby from Mogok, Myanmar, contains rounded mineral inclusions and needles not seen in synthetic ruby.



John Koivula/GIA

The three-phase inclusion in the natural emerald consists of a liquid, a rounded gas bubble, and a cube-shaped crystal.



Alan Jobbins

The flame-fusion synthetic ruby shows curved growth along with gas bubbles without an accompanying liquid or solid. This would not occur in a natural, untreated ruby.

Separating Natural Gems from Synthetics

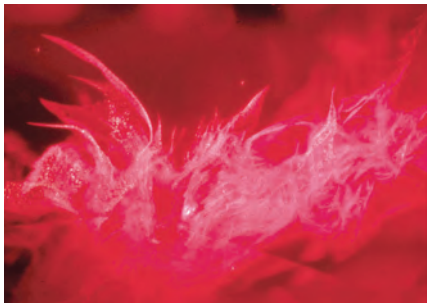
Knowing how synthetic colored stones are made helps you understand the differences between synthetics made by different processes. It also helps you understand how inclusions allow gemologists to distinguish natural gems from synthetics.

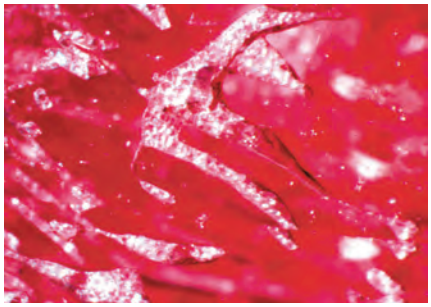
Although synthetics and natural gems are made of the same or similar components and because they look extremely similar, there are often microscopic differences between the two that most gem professionals can recognize.

Inclusions reflect a crystal's growth process, so they can help trained observers decide whether a gem grew in the earth or in a lab. Natural gems often display many more types of mineral inclusions than synthetics, and they often contain inclusions that synthetics don't.

The presence of gas bubbles can be a clue that a colored stone is a synthetic. Gas bubbles do occur in some natural gem materials, including amber and natural glasses like obsidian. But they usually only appear in natural gems as part of a two-phase or three-phase inclusion. Solitary gas bubbles can occur in synthetics. Other inclusions that can occur in synthetics are sometimes described as "fingerprint-like," or as resembling "dripping icicles" or "wispy, smoke-like veils."

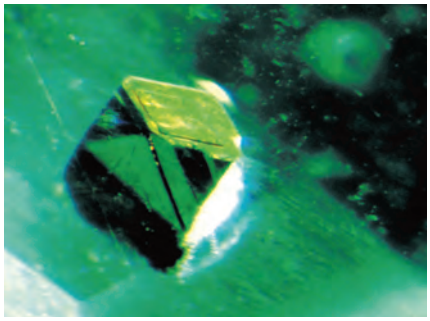
As a gem grows, it gains certain internal and external structures that indicate growth direction. In most natural gems, these structures are always straight or angular, never curved. A synthetic gem can have straight

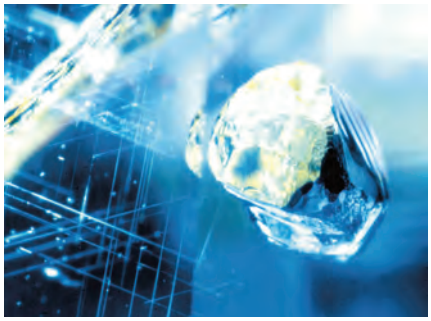




Alan Jobbins

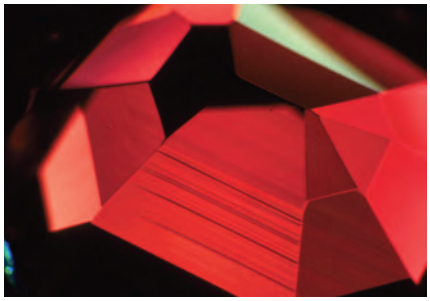
Some inclusions are associated exclusively with synthetics. The synthetic ruby on the left contains "wispy veil" inclusions. The synthetic ruby on the right displays flux particles that resemble dripping icicles and have a coarse texture.





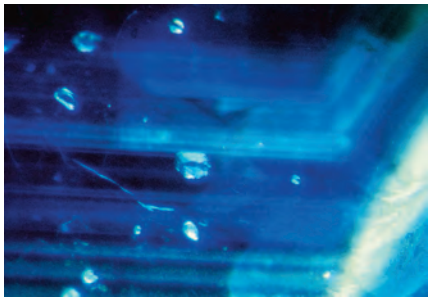
Alan Jobbins

The brass-colored angular pyrite crystal in the emerald (left) and the angular crystal and intersecting needles in the sapphire (right) tell the gemologist that these stones are natural.



John Koivula/GIA

Solution-grown synthetics can show straight or angular growth that's similar to natural gems. An example of straight growth can be seen in the flux-grown synthetic ruby (10x).



Edward Gubelin/GIA

The natural blue sapphire shows angular growth.

or angular growth marks, too, but if they're curved, you can be almost certain that the gem is a synthetic. Curved growth can help gemologists distinguish flame-fusion gems, for example, from natural gems.

Separating synthetic gems from natural ones is one of the most vital tasks a gemologist can perform. The whole industry benefits when separations are made successfully. These important skills are taught in the GIA *Gem Identification* course.

Imitation Gems

- How are imitation gems different from synthetic gems?
- What different kinds of materials can serve as gem imitations?

Imitations are all around us. A woman might wear an inexpensive plastic belt that mimics expensive patent leather. Your dining table at home might feature an easy-to-clean imitation wood grain top. You might have placed a bowl of ceramic "fruit" on top of the table, or a vase of silk or paper blossoms—substitutes for the real thing that won't spoil or wilt.

Anything beautiful, desirable, and difficult to obtain because of cost or rarity is a prime candidate for imitation. That's why there's an imitation made for just about every gem that can be imitated. There are many types of gem imitations, and some are more convincing than others. The thing that makes an imitation different from a synthetic is that it can be made of almost any material, as long as it looks like the gem it's supposed to replace.

Natural Gems as Alternatives

A gem alternative doesn't have to be created by human hands. Natural gems can also substitute for other gems. Historically, red spinel was a ruby alternative fit for royalty because its rich color echoed ruby's celebrated scarlet hue.

If sellers offer jewelry featuring natural replacements without the intent to deceive buyers, then these gems are worthy of the label "alternative." For example, an amethyst pendant can be sold as a less expensive natural alternative to a tanzanite pendant because the two are often similar in color. Or a customer who loves ruby might appreciate a more affordable red garnet as a natural alternative.

Synthetic Gems as Imitations

You've learned about synthetic versions of natural gems. But things get a bit confusing when manufacturers use a synthetic stone to imitate a gem other than its natural counterpart. For example, synthetic spinel can mimic the look of many different natural gems, depending on its color. (Manufacturers control color in synthetics by adding different ingredients.)

Synthetic spinel's accurate reproduction of a wide variety of colors makes it a common choice for imitation birthstone jewelry. As you learned earlier in this assignment, blue synthetic spinel can be used to imitate aquamarine. But synthetic spinel is less accurate when reproducing purples, greens, and darker tones. The development of CZ in darker hues has made it a convincing alternative for those shades.

The violet-blue African zoisite known as tanzanite has soared in popularity in recent decades. As a result, synthetic imitations of the gem have multiplied. Synthetic corundum and YAG have both been grown as tanzanite alternatives.

Orasa Weldon

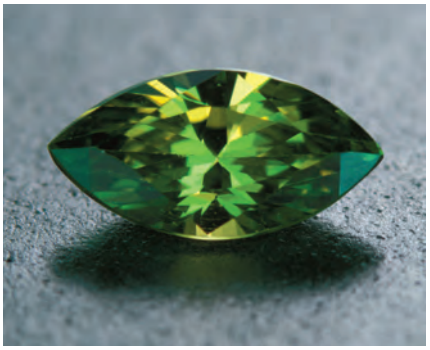
Flame-fusion synthetic spinel can be produced in a range of blue hues of varying tones and saturations. This makes it an effective substitute for natural sapphire and aquamarine.

Courtesy Lauren Stomel Advertising

The flame-fusion method can produce synthetics in a wide range of colors. This is essential to the production of mass-market jewelry.

Maha Tannous/GIA

Synthetic forsterite, made blue by the addition of cobalt during growth, displays strong pleochroism. These features make it a convincing tanzanite imitation. The large cushion-shaped mixed cut weighs 6.15 cts.



Maha Tannous/GIA

Synthetic CZ in some darker tones offers an alternative to synthetic spinel in birthstone jewelry. This 2-ct. green CZ from Russia possesses a deeper green color than synthetic spinel.

In 1999, increasing popularity and demand for the natural gem led to the appearance on the market of a new tanzanite imitation—synthetic forsterite. Forsterite, a natural gem, had been synthesized before in various colors. But this version, a pulled synthetic colored with cobalt, makes a convincing tanzanite imitation. Forsterite's strong pleochroism—the ability to display different hues at different viewing angles—makes it a good match for tanzanite, since tanzanite also shows strong pleochroism.

Robert Weldon/GIA

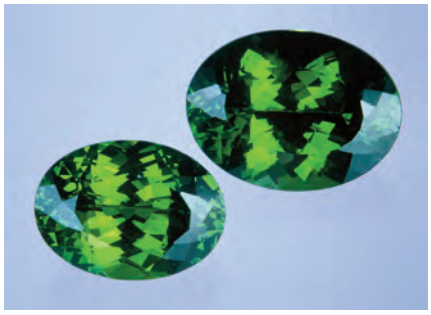
Plastic imitates the distinctive color and patterning of natural malachite in these watches.

Non-gem Materials as Imitations

Manufactured glass is an age-old gemstone imitation that's still used today. The material's ability to imitate a variety of colors makes it hard to distinguish at first glance from the gems it imitates. That's why glass imitations of stones like amethyst, Mexican fire opal, aquamarine, and peridot have turned up in parcels for sale, mixed in with the natural gems they mimic. Of course, gemological tests can quickly reveal the imitations, but it's wise to remember that any so-called gem might actually be a glass imitation.

Of course, glass imitations are not always crafted with deception in mind. For example, attractive cabochons made of fused layers of glass have been sold as imitation agate and tortoise shell.

Plastic is often used to imitate gemstones in inexpensive fashion jewelry or children's trinkets. However, this modern manmade substance has also been manipulated into convincing imitations of organic gems like amber, pearl, and coral, or aggregates like jade, turquoise, and lapis. Plastic is not a durable gemstone imitation—it melts easily during repair work, and it scratches easily because it's so soft.

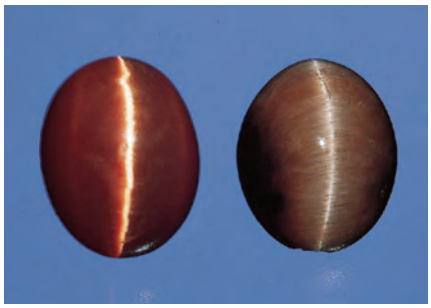


Maha Tannous/GIA

Glass can imitate a wide variety of materials. The green ovals look like peridot, but they were identified as glass. The larger gem weighs 26.82 cts.

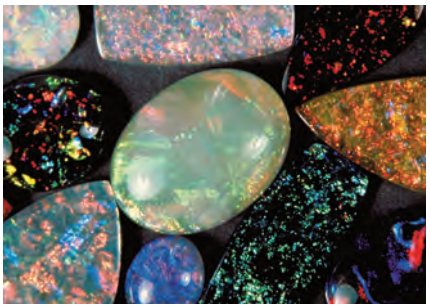
Maha Tannous/GIA

These two fused-glass cabochons (36.95 and 48.82 cts.) imitate the look of natural agate.



Maha Tannous/GIA

Glass can be used to imitate phenomenal natural gems. Of the two tiger's-eye cabochons, the one on the right is a 1.83-ct. heat-treated natural gem and the one on the left is a 2.85-ct. imitation made of optical fiberglass.



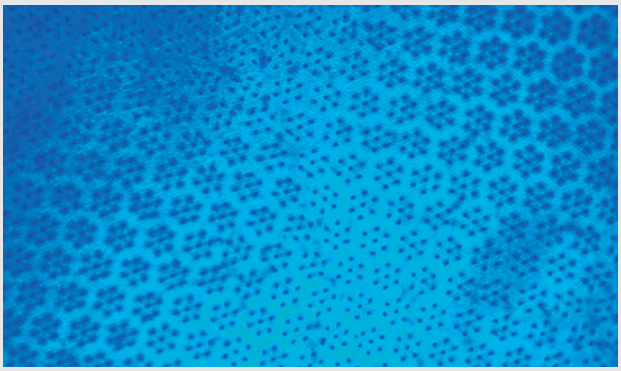
Alan Jobbins

Attractive opal imitations can also be made of glass.

Imitations

Robert Weldon/GIA

Glass can be produced in a number of colors and appearances to effectively imitate a host of natural gem materials.

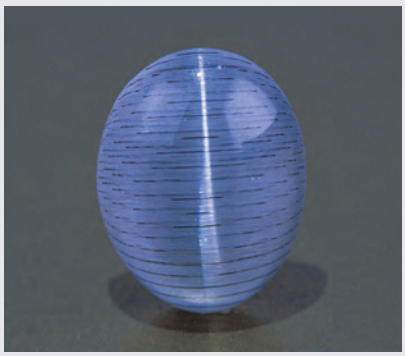


John Koivula/GIA

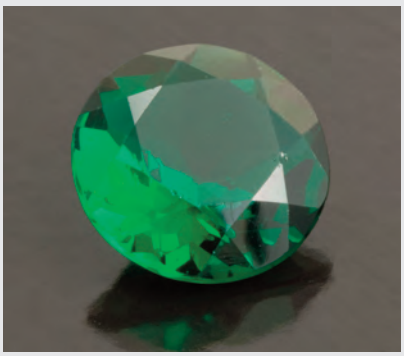
Viewing a glass imitation cat's-eye cabochon vertically under 35X magnification reveals the structure of its optic fiber bundles.

Terri Weimer/GIA

The goldstone glass on the left and the goldstone plastic on the right are popular sunstone feldspar imitations. Magnification shows distinct copper inclusions in both materials.



Bundles of parallel optic fibers can create a cat's-eye effect in glass. The reflective band on this 11.00-ct. cat's-eye glass cabochon is less distinct than the usual cat's-eye display in this type of manufactured gem.



Eric Welch/GIA

Plastic isn't nearly as effective an imitation of transparent gem materials. Facet junctions have a soft molded look, and plastic's heft is much lower than the gems it imitates.

Robert Weldon/GIA

Plastic can effectively imitate some gem materials, especially organic ones like shell, pearl, and amber.

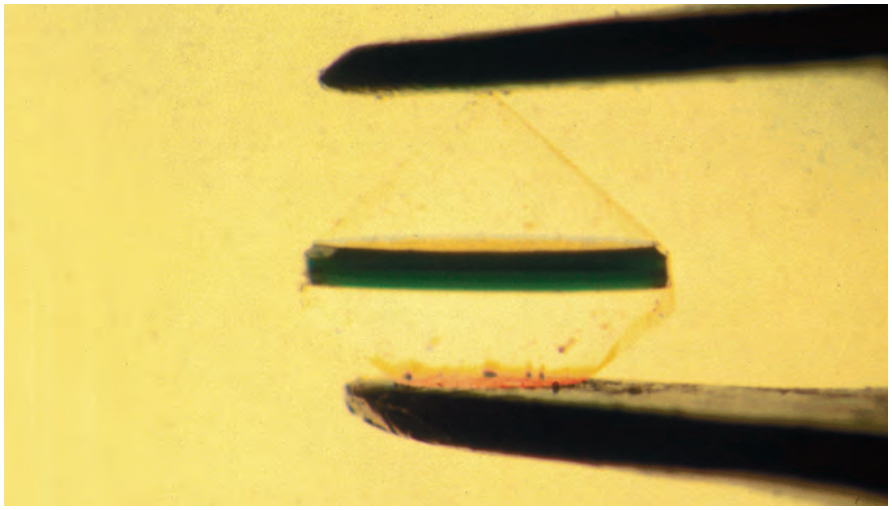
Robert Weldon/GIA

These imitation opalized shells contain opal and matrix fragments in some form of binding agent, probably a resin.

Assembled stone—Two or more separate pieces of material joined to form a unit.

Doublet—Two pieces of material fused or cemented together to form a single assembled stone.

Triplet—A single assembled stone made from three pieces of material fused or cemented together, or from two pieces and a colored cement layer.

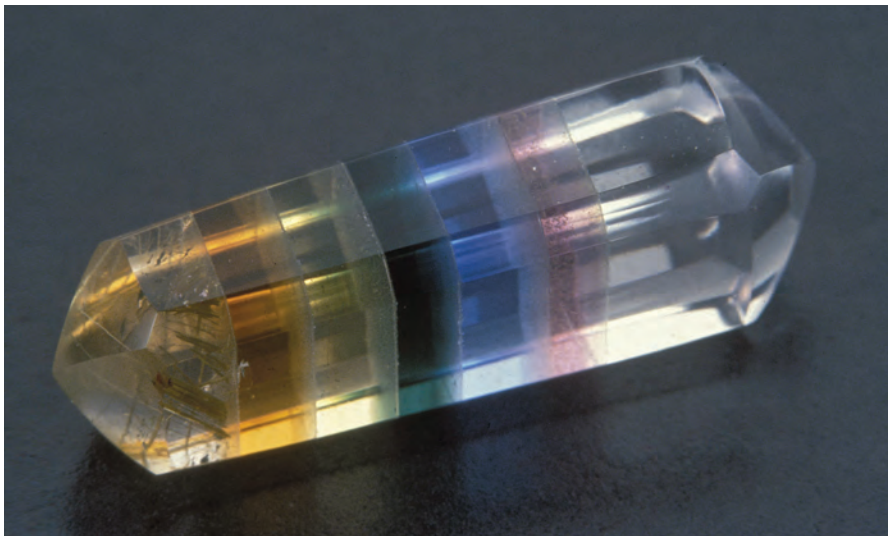


John Koivula/GIA

When viewed through a liquid with a similar refractive index, this synthetic spinel triplet reveals its true composition. The green cement layer at the girdle stands out from the colorless synthetic spinel crown and pavilion.

Tino Hammid/GIA

Assembled stones can contain manufactured or natural materials. These two 10x8-mm triplets were made with plastic imitation opal to provide play-of-color.

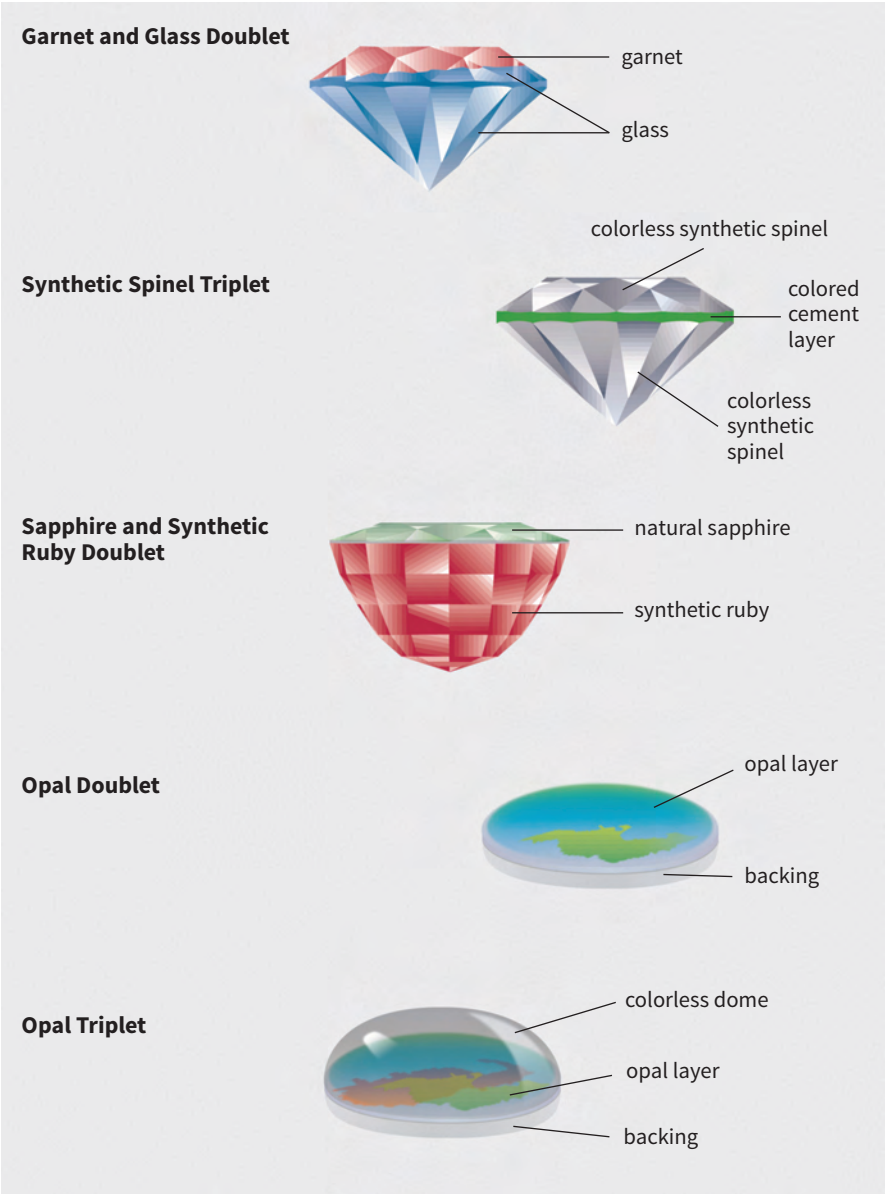


Maha Tannous/GIA, courtesy Bashir Beekzad

Some assembled stones provide a unique combination of contrasting colored gem materials. This 33.83-ct. assembled stone is constructed of a combination of natural and synthetic quartz. The blue and dark green layers are synthetic quartz, as these colors are not found in natural quartz.

Assembled Stones

When manufacturers glue or fuse two or more separate pieces of material together to form a unit, the result is called an *assembled stone*.(Assembled stones are also known as composite stones.) The separate pieces can be natural or manmade. A *doublet* is an assembled stone that consists of two joined segments. A *triplet* has three segments, or two segments and a layer of colored cement. When you look at an assembled stone set in jewelry, the layers should be difficult to distinguish.



Peter Johnston/GIA

Assembled stones are often used as gem imitations because their layers can provide color and durability that the individual materials might not be able to provide as effectively. Illustrated here are a garnet and glass doublet, a synthetic spinel triplet, a sapphire and synthetic ruby doublet, an opal doublet, and an opal triplet.

Shane McClure/GIA

Only the earring on the right contains a natural emerald. The other earring contains a triplet consisting of a rock crystal quartz crown, a green cement layer, and a pavilion made of an undetermined material.

Shane McClure/GIA

Magnification clearly shows the green cement layer at the girdle of an assembled stone. The green cement is also reflected in the green band in the pavilion.

An assembled stone's layers are selected to provide desired color and durability. Assembled stones that imitate natural gems include green synthetic spinel triplets, which serve as imitation emerald. Manufacturers also developed an assembled tanzanite imitation. It's a triplet that consists of two layers of synthetic spinel and one layer of glass. The glue used to cement the materials together contains the violet hue characteristic of natural tanzanite.

Maha Tannous/GIA

Violet-colored synthetic spinel triplets can imitate tanzanite. Because of their structure, triplets can be produced in colors—such as darker greens and purples—that are hard to attain in synthetic spinel.

Maha Tannous/GIA

Some assemblies require a good deal of effort and ingenuity. Even obscure gems are subject to imitation. This plastic-coated assembly imitates a "trapiche" emerald, which has a black hexagonal core and six thin black sections radiating out from its center.

Although manufacturers frequently use doublets and triplets to imitate natural gems, assembled stones are not always imitations. This is the case with natural opal, which sometimes occurs in layers so thin that they need reinforcement to be sturdy enough for jewelry use. Black onyx, plastic, or natural matrix have served as the bottom layers of opal triplet cabochons, topped with a dome made of rock crystal, plastic, glass, or synthetic corundum. Because the opal content is less than that of a solid opal cabochon, these assembled opals are less valuable, but they make good use of precious opal slices that would otherwise be too thin for jewelry use.

Synthetics, Imitations, and the Marketplace

- What are the benefits of synthetic and imitation gems?
- How do synthetic gems and natural gems compare in cost?
- Why is it important for a gem's identity and origin to be disclosed?

Everyone in the colored stone trade benefits from knowing about synthetics and imitations and representing them accurately. Sharing product information about synthetics and imitations helps gem buyers as well as consumers make informed choices in today's complex colored stone market.

Synthetics and imitations exist as a result of human ingenuity, not a natural process, but there is still a place for them in jewelry display windows. Alternatives to natural gems offer many advantages to both consumers and jewelry manufacturers. They can possess the beauty and durability of natural gems for a fraction of the cost.

Shane McClure/GIA, courtesy Our Secret Creations, Beverly Hills, CA

Synthetic gems like these flame-fusion rubies and sapphires can offer the beauty and durability of natural gems for a fraction of the cost.

Synthetics and imitations offer consumers on limited budgets an affordable alternative to fine colored stone jewelry. For example, some people might prefer to pay thousands of dollars for a fine-quality natural emerald. But consumers with less to spend can get the romantic look of emerald for a much lower price by choosing a synthetic or imitation. If a man's wife adores fine cornflower-blue sapphire, but he can't afford to buy it for her, synthetic sapphire in the same beautiful color can give her a similar look at a fraction of the price.

Deception in the Rough

Maha Tannous/GIA

Maha Tannous/GIA

Even natural rough is a candidate for imitation, if the gem it imitates is valuable. This inexpensive 473-ct. smoky quartz crystal was decorated with "matrix" and a green coating to imitate emerald rough (top). After removal of the outer materials, the underlying crystal (bottom) weighed 407 cts.

Gems are rare and dazzling treasures. Most people are naturally attracted to them. If they can't afford the real thing, many people buy and wear alternatives that suggest the beauty of the genuine article. Manufacturers and sellers of imitations offer a legitimate service to consumers. But selling imitations as something other than the clever substitutes they are is unethical. It's also illegal in most countries.

One type of deception occurs in the rough gem market, where buyers purchase rough crystals to fashion into cut gems. The deception takes the form of clever but worthless imitations of diamond and colored stone gem rough.

Because of its rarity, emerald rough is a favorite target for imitation. For the past few decades, quartz crystals masquerading as genuine Zambian emerald crystals have fooled bargain hunting tourists in southern Africa. Many imitations were fragments of clear or smoky quartz glued together with a green epoxy resin and covered over with mica flakes (to imitate the matrix, or surrounding "deposit" materials). Others consisted of single quartz crystals coated with a transparent bluish green plastic and studded with an imitation matrix of crushed granite and mica.

With some artful doctoring, near-colorless topaz crystals can pass as diamond crystals to the untrained eye. In 1997, GIA received two specimens for identification. The crystals were shaped like diamond rough. They also had triangular growth marks similar to those found in diamond rough. However, an examination of the optical and physical properties of the mystery material revealed it to be topaz.

Inclusions of tourmaline and chlorite provided one clue to the rough's true nature—these inclusions don't occur in diamond. Furthermore, the growth marks proved to have been applied by man. The painstaking deception took skill, but it also showed how far people sometimes go in order to create an illusion.

Natural gems like quartz and topaz are not the only materials used to create convincing imitation rough. CZ crystals have been shaped into diamond-like shapes and engraved with growth marks to mimic natural diamond rough. However, CZ has a higher specific gravity than diamond, one giveaway to its true nature.

Inexpensive flame-fusion ruby boules might be fashioned to resemble natural ruby crystals. The synthetic crystals can be fashioned to look like water-worn alluvial crystals, or they might even be heated to induce natural-appearing fractures.

Although it might seem more trouble than it's worth to create fake rough—to say nothing of its dishonesty—remember that any imitation rough probably costs much less to make than the amount it can be sold for if the deception succeeds. In gem-producing countries with unstable economies, the potential profit from one piece of fake gem rough sold to an unsuspecting tourist might be more appealing to the seller than the fear of punishment.

Nicholas DelRe/GIA

These five CZ crystals were shaped and engraved with fake growth marks to resemble diamond rough.

Nicholas DelRe/GIA

These two crystals, fashioned to look like diamond rough, are actually near-colorless topaz.

Maha Tannous/GIA

This 10.85-ct. synthetic ruby was fashioned to imitate a water-worn alluvial natural ruby crystal. Deceptions like this are common in source areas, where unwary buyers are more likely to be convinced that they are looking at the genuine article.

Many websites sell imitation and synthetic jewelry designed to look like famous pieces. This site marketed an imitation of the "Heart of the Ocean" necklace from the popular motion picture "Titanic."

There is a large online market for synthetics and imitations. This advertisement for "lab created gems" shows that proper disclosure and product descriptions are the responsibility of everyone in the jewelry trade.

Gem alternatives can also benefit owners of valuable colored stone jewelry. They can store their natural treasures safely when they travel, and wear the alternative versions instead. Since the alternatives cost far less, there's less financial loss if the jewelry is stolen.

Money matters to jewelry manufacturers, too. They appreciate the fact that synthetics and imitations can offer the advantages of size and color uniformity. Sometimes, because of crystal shape or other reasons, a rough natural crystal can't be cut in certain sizes and shapes. But its synthetic counterpart can. Or an imitation can be manufactured in the precise shape and size needed.

Gem alternatives can also be made in uniformly matched colors. This can be difficult to achieve with natural gems, especially when smaller stones are compared to larger ones. Color control in synthetic crystal rough is especially helpful when a jewelry design requires a set of matched gems. Perfect color matches can be achieved when the manufacturer cuts all the gems for a particular jewelry item from the same piece of synthetic crystal. In addition, many processes result in "batches" of synthetic crystals that are remarkably uniform in color.

Disclosure

In the jewelry industry, the term disclosure means selling goods for what they are. Disclosure should be essential to good business practices, but when it comes to synthetics and imitations, disclosure isn't always so simple. For example, synthetic amethyst can so closely resemble the natural gem that a salesperson might not realize that a ring she just sold as genuine contained a synthetic amethyst. Or in the case of an opal triplet, customers might not understand that the cabochon in a pendant owes some of its beauty and durability to non-opal layers.

Or what about the retailer who purchases a beautiful 2-ct. ruby from a dealer at a gem show thinking it's natural? He sells it to a customer as natural, but when the customer has the gem appraised, it turns out to be lab-grown. Who is responsible for failing to disclose? More importantly, how can the industry make sure that such mistakes don't happen—and guard against deception in general?

KEY CONCEPTS

Gemologists play an important role in ensuring that disclosure becomes the industry standard.

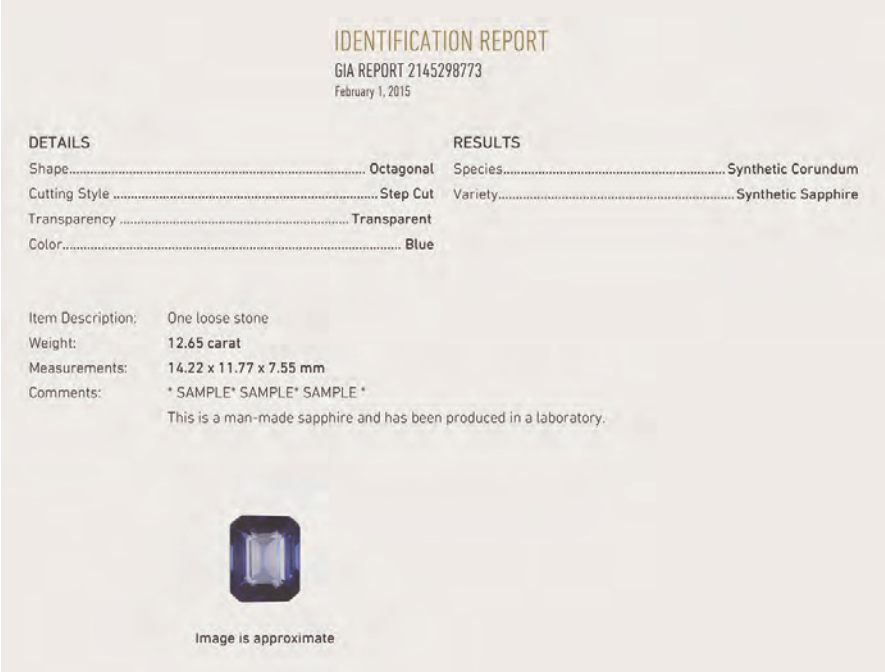
The Gemologist's Role

Gemologists play an important role in ensuring that disclosure becomes the industry standard. That's because gemologists are trained to recognize the subtle differences between various types of gem materials, including synthetics and assembled stones.

A trained gemologist can tell a natural ruby from a synthetic. If the ruby is synthetic, a gemologist can also tell whether it was grown from a melt process or a solution process. Gemologists can even determine the type of melt or solution process used. All these distinctions can be factors in the way gems are identified and sold.

Kevin Schumacher/GIA

Gemologists are trained to recognize the difference between natural gems, synthetics, and imitations. This is a very important skill in today's market, where disclosure is a vital consumer confidence issue.



IDENTIFICATION REPORT
GIA REPORT 2145298773
February 1, 2015

DETAILS		RESULTS	
Shape	Octagonal	Species	Synthetic Corundum
Cutting Style	Step Cut	Variety	Synthetic Sapphire
Transparency	Transparent		
Color	Blue		

Item Description:	One loose stone
Weight:	12.65 carat
Measurements:	14.22 x 11.77 x 7.55 mm
Comments:	* SAMPLE* SAMPLE* SAMPLE *
	This is a man-made sapphire and has been produced in a laboratory.

Image is approximate

Independent reports on a gem's identity, such as this synthetic sapphire report from GIA, increase consumer confidence.

The Industry's Role

Whether a gem is mined, lab-grown, or assembled, it goes through many steps before it reaches the consumer. For the sake of consumer confidence, it's important for the industry to disclose the truth about what's being sold, every step of the way. When you accept money for a gem, you should already know what it is—synthetic or natural, for example. If you don't know for sure what you're selling, you should proceed with caution before offering it for sale. Make sure you know the identity of the material you're dealing with. This can save money or—perhaps more important—your reputation. Don't risk becoming the victim or perpetrator of fraud.

Once you make a sale and a gem turns out to be something other than what you sold it as, the public interprets the transaction as dishonest. It doesn't matter whether the misrepresentation was deliberate or not.

Remember, synthetics and imitations play an important role in the industry. If they are sold for what they are, they are something both buyers and sellers can be proud to deal in, own, and wear. Their versatility brings the beauty of natural gems within reach of everyone, at every market level. They provide valid options that are appropriate for different buyers with differing needs.

Disclosure by every member of the jewelry industry can raise public awareness of natural gems and their synthetic or imitation alternatives, and increase sales at every level. The trained gemologist has an important part to play in giving industry members the knowledge they need to properly disclose the identity of all colored stones.

KEY CONCEPTS

Knowing whether a gem is natural or synthetic is crucial when buying or selling colored stones.

Imitations can be made of a variety of materials, including natural or synthetic versions of other gems.

The process used to produce a synthetic gem can determine its value.

Advances in synthetic crystal growth have been driven mostly by industrial and research demands.

Most synthetic gem crystals are produced by either a melt or a solution process.

Pulling is important for sapphire synthesis because it produces extremely pure, high-quality crystals for technological and science applications.

Solution processes are generally slower and more expensive than melt processes.

Solution processes can synthesize gems that closely resemble natural gems.

Internal and external characteristics can help trained observers separate natural from synthetic gems.

Gemologists play an important role in ensuring that disclosure becomes the industry standard.

Key Terms

Assembled stone—Two or more separate pieces of material joined to form a unit.

Boule—A cylindrical synthetic crystal produced by a melt process.

Ceramic process—A process in which finely ground powder is heated, sometimes under pressure, to produce a fine-grained solid material.

Doublet—Two pieces of material fused or cemented together to form a single assembled stone.

Flame fusion—A process in which powdered chemicals are dropped through a high-temperature flame onto a rotating pedestal to produce a synthetic crystal.

Floating zone —A melt process where a heating unit passes over a rotating solid rod of chemicals until it forms a synthetic crystal.

Flux growth—A process in which nutrients dissolve in heated chemicals and then cool to form lab-grown crystals.

Hydrothermal growth—A process in which nutrients dissolve in a water solution at high temperature and pressure and then cool to form lab-grown crystals.

Imitation gem—Any material that looks like a natural gem and is used in its place.

Melt process—A synthetic-crystal growth method in which the chemical mixture is melted, then recrystallized.

Pulling—A process in which the lab-grown crystal grows from a seed that is dipped into a chemical melt and then pulled away as it gathers material.

Seed crystal—A tiny crystal used as a template to control the size, speed, or direction of growth and the shape of a growing synthetic crystal.

Skull melt—A synthetic-crystal growth method that uses cooling pipes around an interior of melted chemical ingredients.

Solution process—A growth method in which the synthetic crystal grows from a dissolved chemical mixture, sometimes at high temperature and pressure.

Spontaneous nucleation—A synthetic-crystal growth method that starts without a seed crystal.

Synthetic gem—A laboratory creation with essentially the same chemical composition, crystal structure, and properties as its natural counterpart.

Triplet—A single assembled stone made from three pieces of material fused or cemented together, or from two pieces and a colored cement layer.

Questions for Review

- What are the two main categories of synthetic-gem production methods?
- What are some differences between products of melt and solution processes?
- Why is quartz synthesis important?
- What are some basic differences between synthetic and natural gems?
- How are imitation gems different from synthetic gems?
- What different kinds of materials can serve as gem imitations?
- What are the benefits of synthetic and imitation gems?
- How do synthetic gems and natural gems compare in cost?
- Why is it important for a gem's identity and origin to be disclosed?

Treatments

6

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Welcome to *Colored Stones* Assignment 6. With the knowledge you gain from this assignment, you'll be able to:

- Understand the importance of gem treatments in today's marketplace.
- Explain the reasons why gems are treated.
- Follow the legal requirements for gem treatment disclosure.
- Recognize the common types of gem treatments.
- Identify the special care and handling requirements for treated gems.

These rough sapphires owe their deep golden color to heat treatment.

Treatments

Picture an attractive mahogany table. Its finish is dark, and the smooth, polished surface has a warm, lustrous glow. The craftsman who built it took great care with the project. He sanded the surface many times to smooth it and display the wood grain's unique beauty. He filled in any open grains with a special material, then sanded and finished the filled areas to match the surrounding wood.

Zoran Zeremski

Many everyday products, including furniture and clothing, start out as raw materials that must be fashioned and treated before they're useful.

Tino Hammid/GIA, courtesy American Gem Corp.

Treatments add to the variety and affordability of many gems. The intense pink sapphire is a natural color, but the rest owe their attractive colors to heat treatment.

KEY CONCEPTS

Treatments that improve gem appearance and quality increase the supply of commercially important gems.

Treatment—Any human-controlled process, beyond cutting and polishing, that improves a gem's appearance and/or durability and therefore its value.

Next, he rubbed a special stain into the wood, followed by several coats of lacquer, sanding between coats. In the end, he had turned rough mahogany into a beautiful piece of furniture.

Many gemstones go through a similar process between the mine and the retail jewelry counter. Beyond cutting and polishing, they might be dyed, heated, or exposed to radiation to affect their color. And their imperfections might be filled with substances that make them less visible.

As you'll learn, *treatments* are an important part of today's gem and jewelry industry. Without them, supplies of many important gems would be very limited. Treatments improve gem appearance and quality and make more gems available—and affordable—to more consumers. At the same time, they have inspired controversy, as increasingly aware consumers want to know whether the beauty in their gemstones is entirely natural or the result of human intervention.

To be successful in the gem and jewelry industry, you must have an understanding of treatments, of how and why they exist, and of the issues surrounding them. This assignment will help prepare you to buy and sell treated gems with confidence and integrity.

Robert Weldon/GIA

Many gemstones are treated to improve color. Topaz sometimes requires a two-step process. Exposure to radiation gives colorless topaz a brownish hue (left), then controlled heating turns it a more marketable blue (center and right).

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Composite Rubies- From bad to worse

The subject is composite rubies.

The issue is disclosure.

Two lawsuits have been filed against a retailer for falsely representing the gems it sells. Gems sold as natural rubies "were in fact heavily glass filled and often heavily lead-glass treated," said the class action suit.

Two televised sting operations, by "Good Morning America" and by San Francisco's "CBS 5," brought public attention to the scam. On hidden cameras, jewelry department sales staff insisted the stones were ruby and required no special care. Subsequent examination by a gemologist proved them wrong.

Composite rubies are another step in increasingly flagrant gem adulterations.

It began with fracture-filling

Courtesy Jewelry Insurance Issues

Treatments are among the hottest topics in the trade today. The key issue behind them is proper disclosure, which should take place at every wholesale and retail transaction.

Treatments and the Marketplace

- Why are some gems treated?
- How does treatment affect value?
- Why is treatment disclosure important?

Gem rough varies widely in appearance and quality. Very few specimens have beautifully rich color along with almost no surface or internal imperfections. But most gemstones require some sort of improvement to make them more attractive to consumers. That's where treatments come in.

Tino Hammid/GIA

Most gemstones require some sort of treatment. Heat treatment will enhance the color of light-colored sapphires like these.

David Trout/Coffin & Trout Jewelers

Tanzanite's lovely violetish blue is a result of heat treatment. It's one of the best selling colored stones, but without treatment, most would be unmarketable.

Color
Tanzanite

Clarity
Emerald

Inclusions
Amber

Luster
Jadeite

Durability
Turquoise

Gem treatments can create desirable inclusions or improve the color, clarity, luster, and durability of colored stones. These are a few of the gems that benefit from treatments. You'll learn more about them in future individual gem assignments.

Gems are treated for a number of reasons. Treatments can:

- Deepen, change, or remove color
- Improve clarity
- Create or accentuate phenomena and desirable inclusions
- Improve luster
- Improve durability

Many important gems, including emeralds, rubies, and sapphires, are routinely treated in one way or another. Without treatments, the marketable supplies of many gems would decline, and their prices would rise astronomically.

Because a treatment improves a gem in some way, many in the trade call them "enhancements." But the US Federal Trade Commission (FTC)—along with many gem professionals—considers "treatment" the more accurate term.

Treatments and Value

There are two ways to look at the relationship between treatments and value. Treatments can make gemstones more appealing and dramatically increase their value. An example is tanzanite, which can be a less marketable brown color before it's heated to a blue to violet or purple color.

The other way to look at how treatment relates to value is to remember that the absence of treatment makes many stones—fine-quality rubies, emeralds, and sapphires, for example—more valuable than treated stones of similar apparent quality. That's because fine-quality, untreated specimens are rare.

Robert Weldon/GIA, courtesy B. Marini

Robert Weldon/GIA, courtesy B. Marini

Untreated, the mineral zoisite is often brownish in color (left). When heat treatment changes zoisite to an attractive violetish blue, it becomes highly popular tanzanite (right).

Robert Weldon/GIA

It's better for consumers to find out about treatments from you than it is for them to discover them through media coverage. For this reason, you should disclose all types of treatments, including permanent and undetectable ones. This topaz was exposed to radiation and heated to give it an attractive blue color.

Disclosure—Always the Right Thing

"If treatments make such a positive contribution to the market," you might be asking, "Why are they so controversial?" For the most part, it's not the treatments themselves that cause controversy, but whether or not they're adequately disclosed.

Treatment disclosure means fully informing a buyer about any treatment or suspected treatment and its effect on the gem. This includes whether or not the treatment is detectable and how the treated gem compares in value to an untreated one. You must also tell the buyer about any durability concerns, and if the treated gem has any special care and cleaning requirements.

Although gem treatments have a long history, disclosure didn't really become an issue until the latter part of the twentieth century. For example, many dealers knew that emeralds were routinely treated to improve their clarity, but they assumed that since this was fairly well known, there was little need for further disclosure. When they extended this assumption to other treated gemstones, the result was that even ethical retail salespeople weren't aware enough of treatments to be able to disclose them to their customers.

Today's consumers are much more aware of treatments and expect to be told if they're buying a treated gem—or even if treatment is a possibility.

Nutrition Facts

Serving Size 1 cup (228g)
Serving Per Container 2

Amount Per Serving

Calories 250	Calories from Fat 110
	% Daily Value*
Total Fat 12g	**18%**
Saturated Fat 3g	**15%**
Cholesterol 30mg	**10%**
Sodium 470mg	**20%**
Total Carbohydrate 31g	**10%**
Dietary Fiber 0g	**0%**
Sugars 5g	
Protein 5g	
Vitamin A	4%
Vitamin C	2%
Calcium	20%
Iron	4%

* Percent Daily Values are based on a 2,000 calorie diet. Your Daily Values may be higher or lower depending on your calorie needs:

	Calories:	2,000	2,500
Total Fat	Less than	65g	80g
Sat Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2,400mg	2,400mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

US Food and Drug Administration

Today's consumers expect accurate and detailed information about the products they buy. There are many information sources available to them, including government agencies and the Internet.

Gemstone Enhancement Codes*

N = Not Enhanced	I = Impregnation
D = Dyeing	R = Irradiation
HP = Heat & Pressure	C = Coating
O = Oiling/Resin	H = Heating
SC = Special Care	L = Lasering
CMP = Composite	U = Diffusion
B = Bleaching	ASBL = Assembled
F = Filling	W = Waxing/Oiling in Opaque Stones

*Codes and type of treatments must only be used as directed in the Gemstone Information Manual, available at www.agta.org

Courtesy American Gem Trade Association

Treatments should be disclosed with every transaction, including those between members of the trade. The AGTA provides coded treatment disclosure guidelines for use on invoices.

The disclosure issue is complicated. Some treatments are permanent and virtually undetectable. Others are so common that some in the trade simply fail to mention them. Government bodies and trade organizations have treatment disclosure guidelines that are constantly being reviewed and updated. These include the FTC as well as the American Gem Trade Association (AGTA), the American Gem Society (AGS), and CIBJO, the International Jewelry Confederation (CIBJO stands for its French name—Confédération Internationale de la Bijouterie, Joaillerie, Orfèvrerie, des Diamants, Perles et Pierres).

Federal Guides for the Jewelry, Precious Metals, and Pewter Industries:
https://www.ecfr.gov/cgi-bin/text-idx?SID&node=pt16.1.23&rgn=div5

CIBJO Guidelines:
https://www.cibjo.org/the-guidelines/

AGTA Guidelines:
https://agta.org/resources/

Laboratory Treatment Terminology:
https://www.gemstone.org/mission/cdc

It's GIA's position that any treatment—even if it's only suspected—should be disclosed as part of every transaction, whether it's between dealers, between a dealer and a retailer, or between a retailer and the consumer.

There have been some spectacular civil cases involving the lack of disclosure. In the US, a court case in the late 1990s focused media attention on undisclosed emerald treatments. The negative attention depressed the emerald market for months. Then, in the early 2000s, large quantities of pinkish orange sapphires sold as heat-treated turned out to owe their color to beryllium lattice diffusion, which you'll learn about later. Exposure of the deception damaged trust between corundum sellers and buyers.

JCK THE INDUSTRY AUTHORITY NEWS & TRENDS HOW TO MAGAZINE SHOWS JCK NEWS DAILY

Resuscitating Emerald Sales

November 1, 1999 by LARRY FREDERICK

lfrederick@calmers.com

Is there a sadder story in the jewelry industry than the calamity that's struck emeralds? Until just a couple of years ago, the green stone remained glamorous and popular, with fine specimens commanding up to $2,700 a carat wholesale. Today emeralds languish as jewelry's déclassé stones. Consumers are suspicious of them, prices are off 50% or more, and emerald dealers are going out of business.

We all know the reason: TV exposés, publicity about the infamous Fred Ward case, and personal experience undermined consumer confidence. People were appalled to learn not only that emeralds are enhanced with fillers but also that the treatments don't last and sometimes even turn the stone a sickly hue.

Now a new Gemological Institute of America study shows consumers are justified in their wariness (see Gem Notes, p. 36 in this issue). Those treatments turn out to be more numerous.

JCK NEWS DAILY NEWSLETTER

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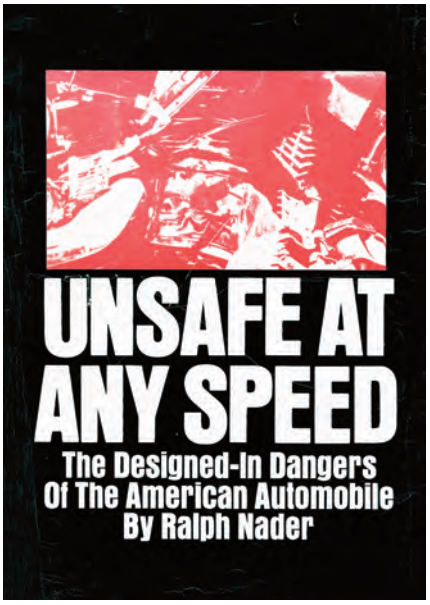
Courtesy JCK Magazine

Nationwide media attention on the lack of disclosure of emerald treatments by jewelers caused lower prices and lost sales for months. The market eventually recovered, but the events made it clear that market disasters can result if treatments aren't always disclosed.



The book *Unsafe at any Speed* is considered by many to be one of the most important works of modern consumerism. Written by Ralph Nader and published in 1965, it revealed automobile safety problems and signaled a turning point in consumer protection awareness.

The point is this: Disclosing all treatments is the honest and ethical thing to do. In today's society, failure to disclose can bring dire consequences, ranging from a ruined reputation to the loss of a thriving business. Such failures also focus negative media and consumer attention on an industry that depends on public trust and respect to survive.

Types of Treatments

- What are the most common treatments?
- What stones are commonly treated?
- How durable are some gem treatments?

One of the earliest descriptions of gem treatments is contained in the works of Pliny the Elder, a Roman scholar who lived between 23 and 79 AD. His 37-volume *Natural History* contains information on biology, astronomy, and many other topics, including gemstones. In his celebrated works, Pliny describes using oils, dyes, and foils to enhance gem appearance. These treatments are still used today.

Dyeing, an earlier Egyptian work that dates back to 200 BC, contains 74 recipes for dyeing pearls and other gemstones. Many of these methods are still employed—like the one that described how to "crack" the surface of a gem to improve its absorption of dye. Other recipes from *Dyeing* have fallen out of favor, such as this one for cleaning and whitening a pearl:

"When a pearl becomes dull and dirty from use, the natives of India are accustomed to clean it in the following way. They give the pearl to a rooster to eat in the evening. In the morning they search the droppings and verify that the pearl has become clean in the [bird's digestive system]; and, moreover, has acquired a whiteness which is not inferior to the original."

KEY CONCEPTS

To help build trust in the gem and jewelry industry, all treatments—even suspected or probable treatments—should be disclosed as part of every transaction.

Georgius Agricola/De Re Metallica

This illustration of a glass furnace is from a book on metallurgy written in 1556. This type of furnace was also probably used to heat-treat gemstones.

Today, there are treatments that ancient scholars never could have dreamed of. Some modern treatments are so complex that they present new detection challenges and add to the wide range of durability concerns.

Gem Identification

Technology is advancing rapidly in today's gemological world. New treatments and synthetics are appearing faster than ever before. That's why anyone serious about being successful in the gem and jewelry industry needs up-to-date gemological training.

This course provides much of the information you need. When you complete it, you'll know a lot about gemstone treatments, about the properties of many commercially important gems, and much more. All of that will serve you well if you go on to the GIA *Gem Identification* course.

Gem Identification will teach you the steps and procedures involved in identifying gemstones. You will also learn detection techniques for many treatments.

Some of the topics include:

- Magnification techniques
- Determination of refractive index (RI) and other optical properties
- Spectroscopic analysis
- Selection and use of the proper equipment

Your instructor can help you find out more about *Gem Identification* as well as other GIA courses.

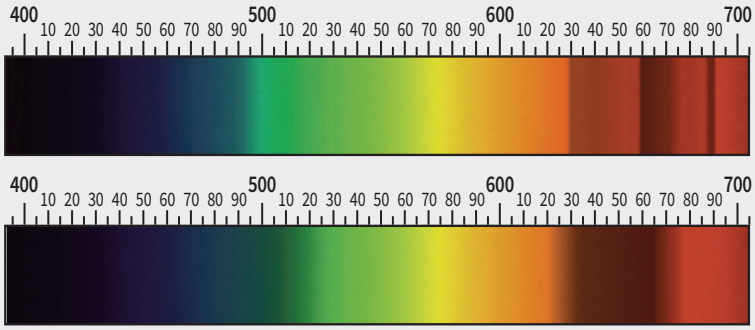
Eric Welch/GIA

Today's jewelry profession encompasses a world filled with emerging technologies and rapidly changing information. Continuing education is the best way to stay ahead of this complex business environment.

The GIA *Gem Identification* course prepares you for a role in the rapidly advancing gem industry by teaching you the steps and procedures to follow when identifying gemstones and their treatments.

Shane McClure/GIA

Detection is the first step on the way to disclosure. Detection of most treatments requires up-to-date gemological training. This red diffusion-treated corundum shows a dark ring around the girdle when it's immersed in liquid.



Once you're trained in its use, the spectroscope can help you identify some gems and treatments. The spectrum of naturally colored green jadeite (top) displays a characteristic absorption pattern of bands and lines in the red area. Dyed green jadeite, on the other hand, shows an absorption pattern with only a single broad fuzzy band (bottom).

Robert Weldon/GIA, courtesy Mozambique Gems

These copper-bearing Mozambique tourmalines—an 88.07-ct. loose gem and an 8.67-ct. example set in a white gold ring—were heated to produce their characteristic "neon" color.

Fred Ward/GIA

Even today, heat treatment of gems sometimes involves primitive methods that have been used for centuries.

Heat treatment—A treatment in which a gem is exposed to rising temperatures to change its appearance.

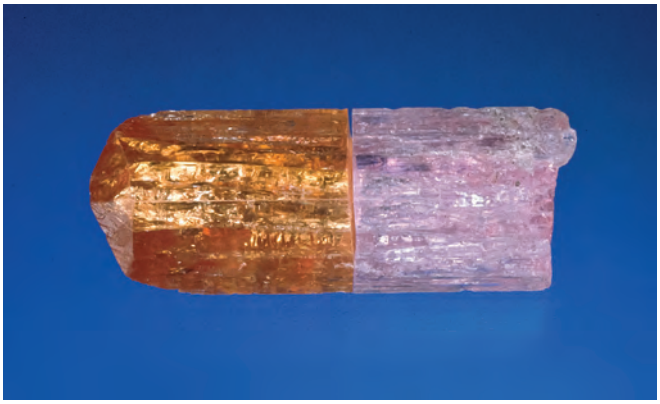
KEY CONCEPTS

Gems that are commonly heat-treated include corundum, tanzanite, zircon, topaz, aquamarine, and amber.

Heat Treatment

Heat treatment—changing a gem's appearance by exposing it to rising temperatures—is an old process and possibly the most widespread in use today. An estimated 95 percent of corundum, and virtually all tanzanite, is heat-treated. Heat treatment is also commonly applied to zircon, topaz, aquamarine, and amber, and occasionally to tourmaline, some quartz varieties, morganite beryl, demantoid garnet, spinel, and even some pearls.

The effect of heat treatment is not always predictable, but it's generally stable and permanent under normal wear. Heating can lighten, darken, deepen, or completely change a gem's color. For example, some light or

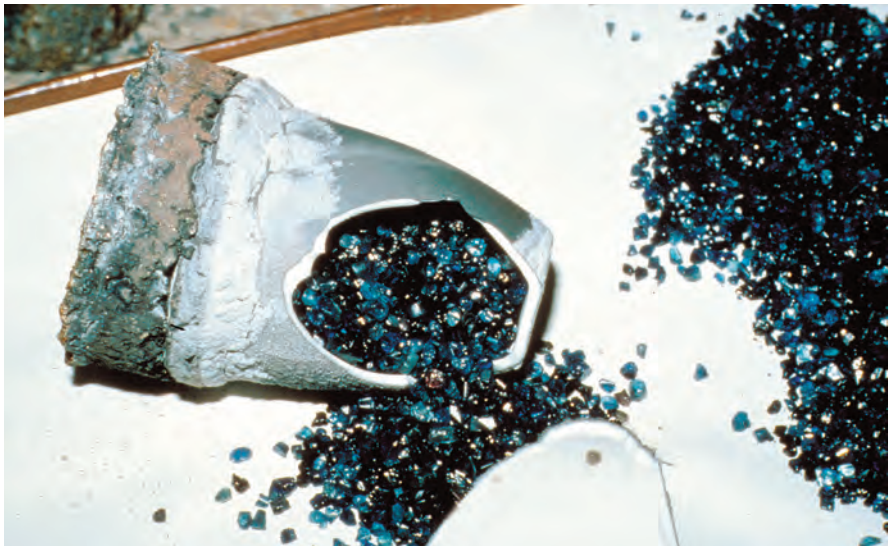


Shane McClure/GIA

Topaz that contains chromium can become pink after just a few minutes of heat treatment. This crystal was divided in half to show the color difference between untreated and treated rough.

Tino Hammid/GIA, courtesy David Humphrey

Heat treatment can change certain types of zircon from a brown color to a much more marketable blue color. Most blue zircon on the market today is the result of this treatment.



Terrence Coldham

These dark greenish blue sapphires from Australia required high temperatures to improve their color.

Simple and inexpensive furnaces are routinely used today to treat gemstones.

grayish corundum turns blue when it's heated. And heating can improve the transparency of some dark blue sapphires and remove the blue component of purplish rubies to make them more red.

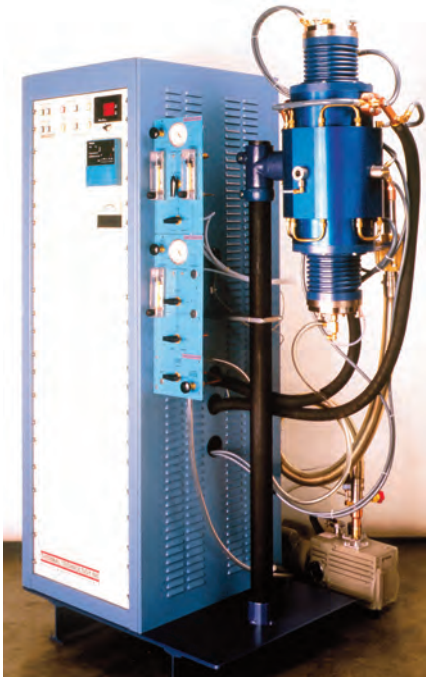
Amber can be heated to improve color, clarity, and hardness. Heating of some copper-bearing tourmalines produces pure blues and greens from stones that might start out grayish blue or violet.

Heat treatments range from the simple to the sophisticated. Some treatments require very low temperatures: A gem is simply held over a flame until the desired effect is achieved. In other cases, gems are placed in expensive computer-controlled furnaces, surrounded by gases and other substances, and heated to temperatures just short of their melting points.

Some factors—alone or in combination—are essential to the success of heat treatment. These include a gem's chemical composition and whether it's from a metamorphic or igneous deposit. Physical properties such as the gem's melting point and the presence of inclusions and fractures can also affect the outcome. Other factors include temperature control and atmosphere and pressure during treatment.

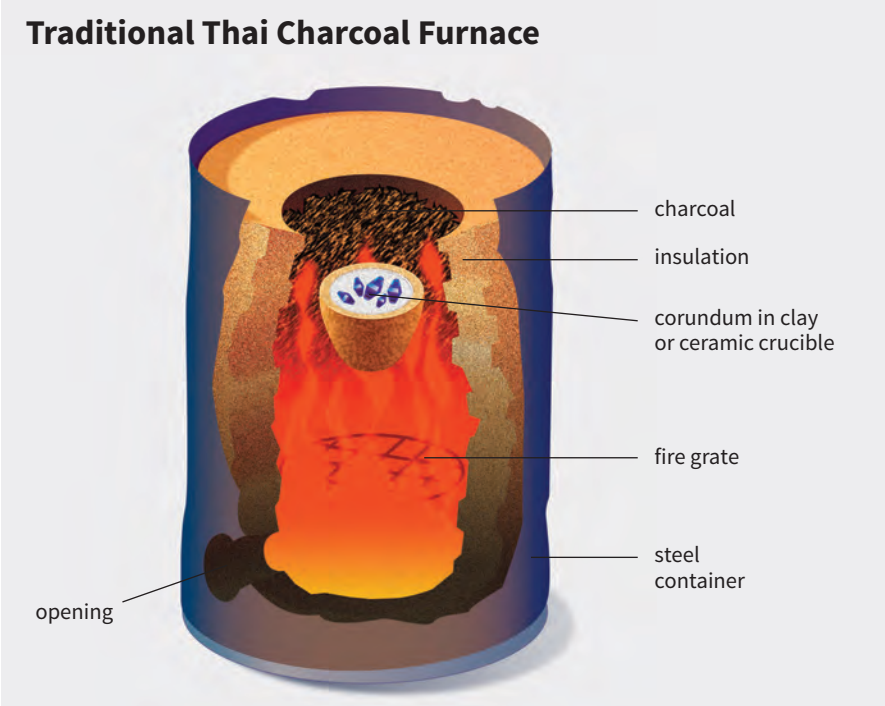
Temperature control isn't only about specific degree settings. It also includes control of the rate and duration of heating. For example, it takes a few minutes of relatively low heat— 400°C (752°F)—to turn some topaz pink. Other gems, such as ruby and sapphire, might require higher temperatures and longer exposure times. The rate and duration of cooling can also be an important factor.

Atmosphere and pressure variations include the gas or other substance that surrounds the gem as it's heated. A gem heated over an open flame is surrounded by oxygen. For some treatments, the gems must be surrounded by other gases—or by materials like sand—to achieve the desired results.



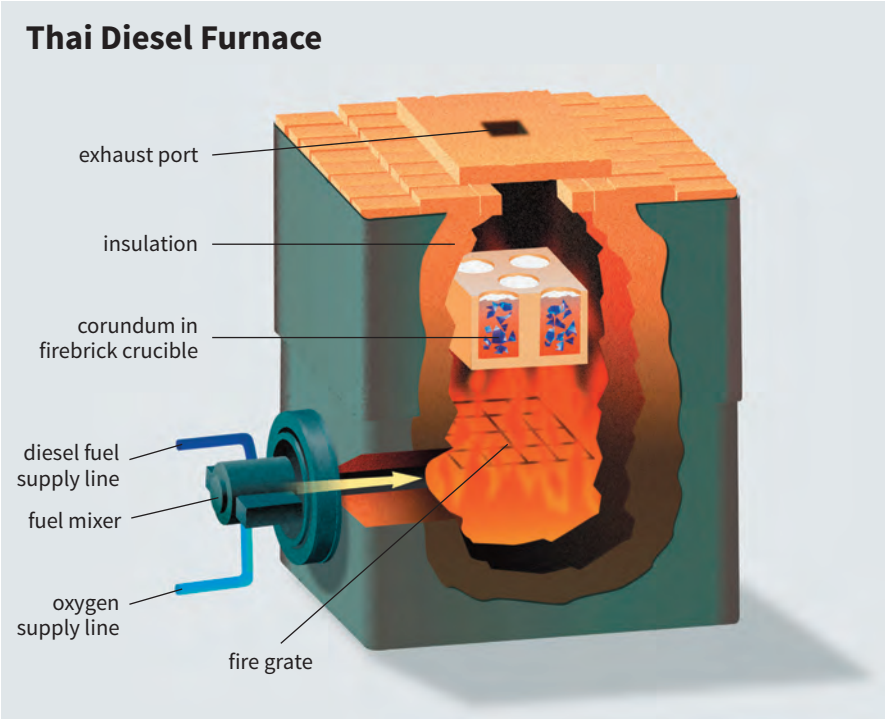
Thermal Technology, Inc.

There are highly sophisticated—and very expensive—computer-controlled furnaces that can precisely control temperature, rate of heating and cooling, and treatment environment.



Peter Johnston/GIA

Gem treaters in Thailand pioneered commercial heat treatment during the 1960s. At first, they enhanced and adapted existing charcoal-fueled furnaces.



Peter Johnston/GIA

Later, they developed more sophisticated diesel-fueled models that reached higher temperatures and allowed more precise temperature control.

As you learned in Assignment 4, many color-causing reactions in gems result from an interaction between electrons and light. So controlling the atmosphere can influence the treatment's outcome. For example, the presence of oxygen during treatment produces more saturated color in some pale yellow sapphires. Heating some light blue sapphires in the presence of another gas, like nitrogen, causes their color to deepen. This occurs because corundum's color-causing trace elements gain or lose electrons, depending on the treatment atmosphere.

When a gem is heated to a very high temperature in an enclosed space, and it's surrounded by oxygen—in what's called an *oxidizing environment*—the gem's trace elements lose electrons. The same trace elements gain electrons if treaters use a *reducing environment*, where the gem is surrounded by gases other than oxygen, like nitrogen or a hydrogen-nitrogen mixture, or by substances like sugar, oil, or glycerin.

While the loss or gain of electrons might seem insignificant, it's enough to affect the way the gem absorbs light. You've already learned how selective absorption of visible light causes an object's apparent color. A reducing environment can make pink sapphires look more purple, while an oxidizing environment gives them a purer pink hue.

Heat can also destroy color centers—structural defects in a gem's atomic structure that affect the way it absorbs light. Changes in color centers cause brown topaz to turn colorless, and amethyst to turn lighter purple, or to yellow or green.

KEY CONCEPTS

When certain trace elements within a gem lose or gain electrons during heat treatment, it can change the way the gem absorbs light, altering its color.

Oxidizing environment—An oxygen-rich environment that surrounds a gem during heat treatment, causing certain color-causing trace elements to lose electrons.

Reducing environment—An oxygen-poor environment that surrounds a gem during heat treatment, causing certain color-causing trace elements to gain electrons.

Heat Treatment of Corundum

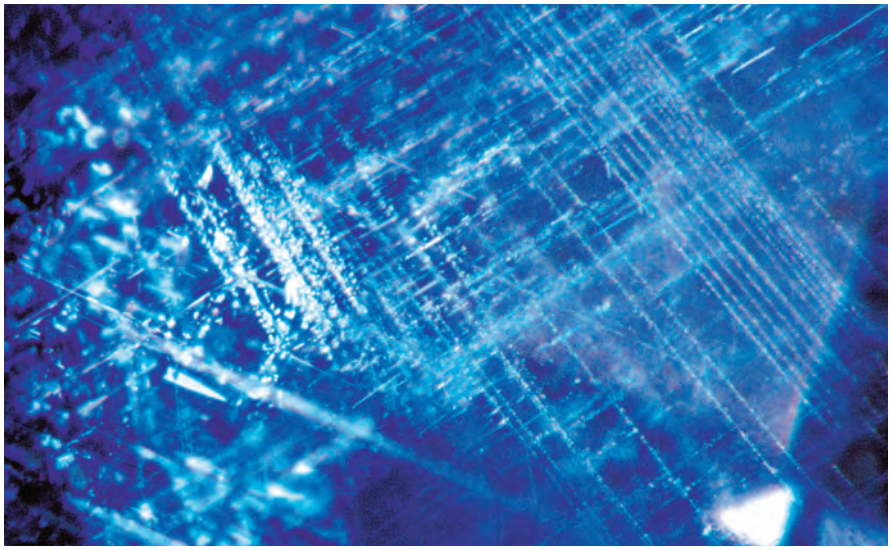
Heat is by far the most common corundum treatment. Depending on the starting material and treatment conditions, it can improve blue color and create golden, yellow, and orange colors in sapphires, remove dark violet cores from rubies, lighten dark material, and reduce violetish or greenish tints.

John Emmett

This thin section of a Mong Hsu ruby crystal clearly shows its almost-black core. Heat treatment would remove the dark color and improve the stone's marketability.

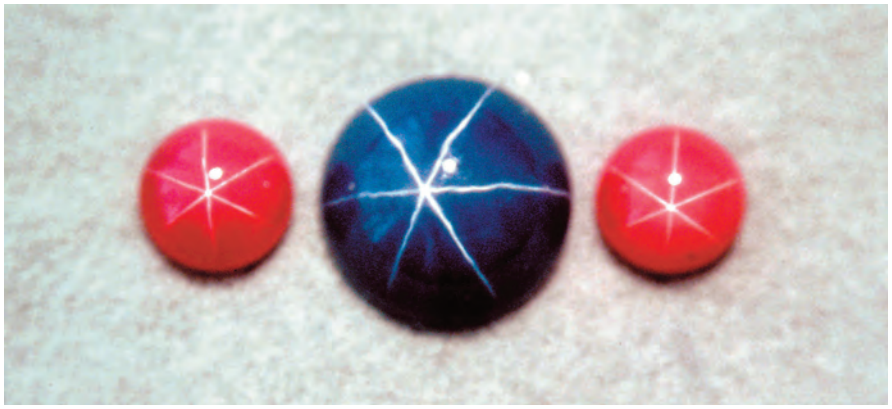
Adi Peretti

Untreated rubies from Mong Hsu, Myanmar, often contain dark violet zones at their cores. This prevents them from being commercially marketable.



John Koivula/GIA

The high temperatures of heat treatment can leave clues behind for the trained gemologist to detect. These include partially absorbed or broken silk in corundum.



Kurt Nassau/GIA

Since the 1950s, gem treaters have used heat followed by slow cooling to produce asterism in flame-fusion synthetic corundum with high titanium content.

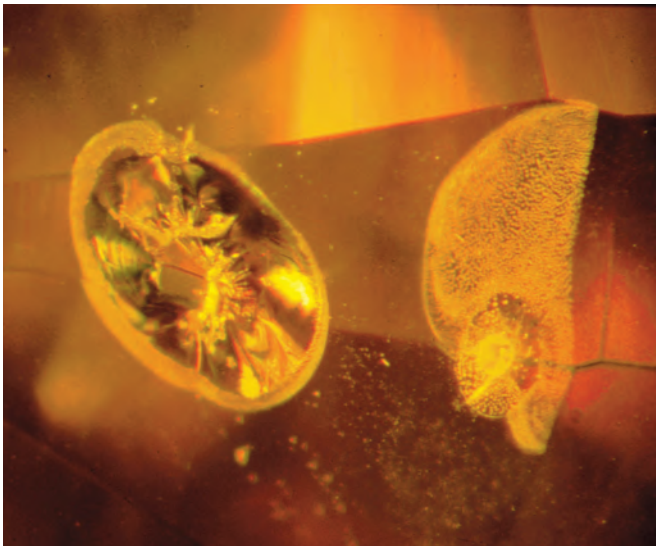
KEY CONCEPTS

Heat treatment can alter corundum color and create or eliminate phenomena and inclusions.

Heat treatment can also improve corundum clarity and transparency by partially removing silk. Many rubies from Myanmar and Vietnam contain rutile silk inclusions, which are composed of titanium and oxygen. Treaters have found that heat treatment at temperatures between 1250° and 1700°C (2282-3092°F) in an oxidizing environment improves clarity by causing the rutile needles to "dissolve" back into the host crystal's lattice as titanium oxide.

Heating can also have the opposite effect, creating silk to form stars where there were none. Synthetic corundum is heated to temperatures above 1700°C (3092°F) for as long as 14 days, then slowly cooled. The high, prolonged temperature and slow, controlled cooling cause the titanium to combine with oxygen and crystallize into rutile. While this can create

The high temperatures reached during heat treatment are often close to the melting point of corundum. This can damage the gem's surface, often requiring repair. Gemologists look for melted areas on the girdle that might have been missed during the repolishing process.



John Koivula/GIA

Other characteristic heat-treatment signs are stress fractures—also called discoid fractures—around the remnants of mineral crystals.

the star effect in synthetic corundum with high titanium content, it works only rarely with natural corundum, which seldom contains enough titanium to form silk.

The signs of heat treatment can be obvious under magnification. It can damage or melt inclusions or cause them to expand and crack the surrounding material, creating stress fractures. Heat treatment can also damage facet surfaces, making repolishing necessary. Some damaged areas can remain after repolishing, and the process might also add extra girdle planes.

Heat-treatment methods are rapidly evolving and becoming more refined. Stones that were treated decades ago might be treated again using new techniques and returned to market. Advances might come from individual experimentation or from consultation with scientists who analyze rough and recommend ways to achieve the desired outcome. Even when a treatment is unsuccessful, enterprising individuals can experiment by varying treatment conditions. Exact treatment processes are often proprietary and closely guarded.

Some practitioners specialize in particular types of stones. Many of today's treaters use multi-step "burns" for corundum, varying treatment times, temperatures, environments, and even oven types. For example, blue sapphire might first be heated in a gas furnace in a reducing environment and then reheated in an electric furnace that allows more precise control of atmosphere, temperature, and heating and cooling rates.

Some low-temperature blue sapphire treatments might take 30 days to achieve the desired results, while others can be completed in less than 90 seconds.

Robert Weldon/GIA, courtesy B&B Fine Gems

This fine 9.10-ct. Mozambique ruby was enhanced by low-temperature treatment.

KEY CONCEPTS

Low-temperature heating can improve the appearance of ruby and pink sapphire by removing blue color zones.

Low-temperature Treatment to Improve Ruby Color

As you learned in Assignment 4, blue color in corundum is caused by an intervalence charge transfer between iron and titanium. Heating in an oxidizing environment causes these color-causing trace elements to lose electrons, shutting down the charge transfer reaction.

Miners in the border regions of Thailand and Cambodia produced considerable quantities of basalt-hosted ruby in the 1980s. Many of these gems displayed a bluish or purplish color component that diminished their value. Heating them at relatively moderate temperatures of 800° to 1250°C (1472-2282°F) in an oxidizing environment removed the blue color, resulting in a more marketable pure red.

Mozambique has been the leading source of commercial and high-quality ruby since 2009. While many Mozambique rubies are subject to conventional high-temperature heating, others are treated in Sri Lanka at much lower temperatures. Low-temperature treatment can enhance the color of red to pink corundum by removing blue color zones.

In 2015, GIA researchers confirmed that temperatures of approximately 550° to 750°C (1022-1382°F) caused the blue color component to decrease noticeably in many gems. In contrast to prolonged treatment processes, the so-called "snakebite" technique uses an acetylene torch and the same moderate temperatures, and takes less than 90 seconds to eliminate the blue color in some rubies and pink sapphires.

Vincent Pardieu/GIA

These purplish red basalt-hosted rubies from Pailin, Cambodia, are typical of the material that made up much of the world's ruby supply in the 1980s and early 1990s.

Robert C. Kammerling/GIA

A dealer at the rough gem market in the Thai border town of Bo Rai sorts parcels of heated ruby for world markets.

Low-temperature treatments can greatly improve corundum color, but they are much more challenging to detect. It's not impossible, however: Using high magnification and fiber-optic lighting, GIA researchers have demonstrated that many inclusions are affected by low-temperature heating. In many cases, they detected fractures around crystals, especially larger ones.

Unaltered rutile needles are the classic signs of an unheated ruby or sapphire. However, these inclusions only begin to dissolve back into the gem's crystal structure at temperatures above 1250°C (2282°F). This means their presence doesn't provide absolute evidence that the stone is unheated, just that the gem wasn't subjected to temperatures high enough to destroy the needles. Many laboratories use the phrase "no indications of heating" to reflect the challenge of detecting low-temperature heating.

KEY CONCEPTS

Low-temperature heating of corundum is much more challenging to detect than higher-temperature heating.

Improving the Clarity of Dark Blue Sapphires

In the 1960s, treaters in Thailand were heating large quantities of Australian basalt-hosted dark blue sapphire to clarify cloudy material. The same process was later applied to similar material from Thailand, Cambodia, China, and Nigeria.

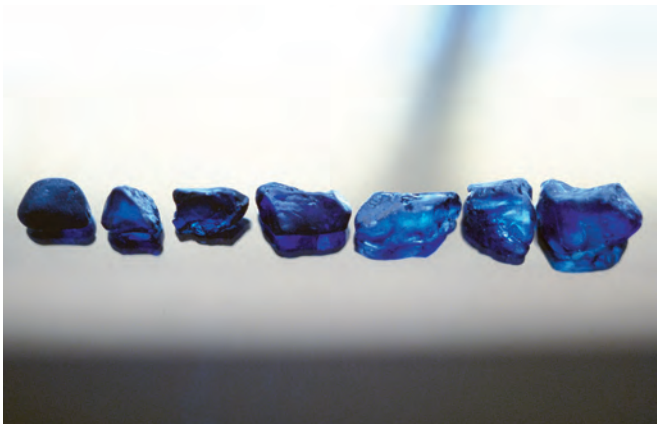
Material from these locations can contain needles, dust-like particles, or mineral clouds. Heating at temperatures between 1250° and 1700°C (2282-3092°F) completely removes these inclusions, reducing or eliminating their effect and making the gems more transparent. Heating times depend on the nature of the inclusions: Gems with coarser inclusions require longer heating times.

The process led to widespread availability of commercial-quality dark blue sapphires, causing generations of sapphire consumers to become accustomed to their rich color.

Vincent Pardieu/GIA

Much of the commercial-quality ruby from Mozambique requires treatment to remove blue coloration and produce a purer red hue.

Vinod Kuriyan/ICA



Vinod Kuriyan/ICA

These basalt-hosted dark-blue sapphires from Australia display a silky appearance prior to heat treatment (left). Heating them to between 1250° and 1700°C (2282-3092°F) greatly improved their transparency (right).

Robert Weldon/GIA, courtesy B&B Fine Gems

Heat treatment produces some exceptional gems, including this fine emerald-cut 33.16-ct. Sri Lankan blue sapphire.

KEY CONCEPTS

Producing blue color in geuda sapphire requires high-temperature heating in a reducing environment, followed by relatively rapid cooling.

Geuda—Milky, grayish, or brownish corundum that can be treated to a fine blue color.

Vinod Kuriyan/ICA

In the 1980s, Thai treaters discovered that careful heating could convert milky geuda corundum like these into vibrant blue gems.

Brendan Laurs/GIA

The top Sri Lankan treaters have caught up with the Thais and compete actively for the world market's treatable corundum. This Sinhalese-made "Lakmini" furnace is used to heat-treat corundum in Madagascar.

Developing Blue Color in Milky Sapphire

In the 1980s, the Thais developed methods for heating milky, translucent Sri Lankan sapphire to a very attractive bright, saturated, transparent blue. Called *geuda* (GOO-dah) the starting material contains titanium impurities that give it a characteristic milky white to brownish "tea" color.

Sapphire's blue color is caused by an intervalence charge transfer between titanium and iron. In geuda, the titanium is locked into the titanium oxide rutile inclusions. Heating the geuda to temperatures around 1250°C (2282°F) dissolves the rutile into the sapphire's crystal lattice and makes the titanium available for the charge transfer. The treatment uses a reducing environment to alter the iron ions for participation in the charge transfer. The heated stones then have to be cooled rapidly to prevent the titanium from recrystallizing into rutile.

This treatment has made gem-quality blue sapphire much more available in the market. Another advantage is that dissolving the inclusions also improves clarity.

Today, geuda-type sapphires from Sri Lanka and Madagascar are often heated in a gas furnace first and then in an electric one for several days, up to a month. Sri Lankan sapphires that were originally treated in gas furnaces are being reheated in electric furnaces for further color improvement.

Vinod Kuriyan/ICA

Vinod Kuriyan/ICA

Before heating in an oxidizing environment, the colors of these Sri Lankan sapphires are pale yellow with a greenish color component (top). After heating, the same sapphires show some stronger golden yellow colors (bottom). Treatment also improved their transparency and brightness, and the greenish tint is gone.

Developing Yellow Color in Sapphire

Also in the 1980s, Thai treaters developed a way to produce strong yellow and orange colors in Sri Lankan sapphires. This treatment usually involves heating pastel-colored corundum in an oxidizing environment. Exposure to radiation can produce a similar saturated yellow, but the resulting color is unstable.

Tino Hammid/GIA

Heat treatment in the presence of a flux improved the appearance and value of these rubies from Mong Hsu, Myanmar.

Flux—A compound that can dissolve another compound at a lower temperature than its own melting point.

Flux healing—Heat treatment in the presence of a flux that results in the sealing of a fracture or cavity.

Flux Healing of Ruby

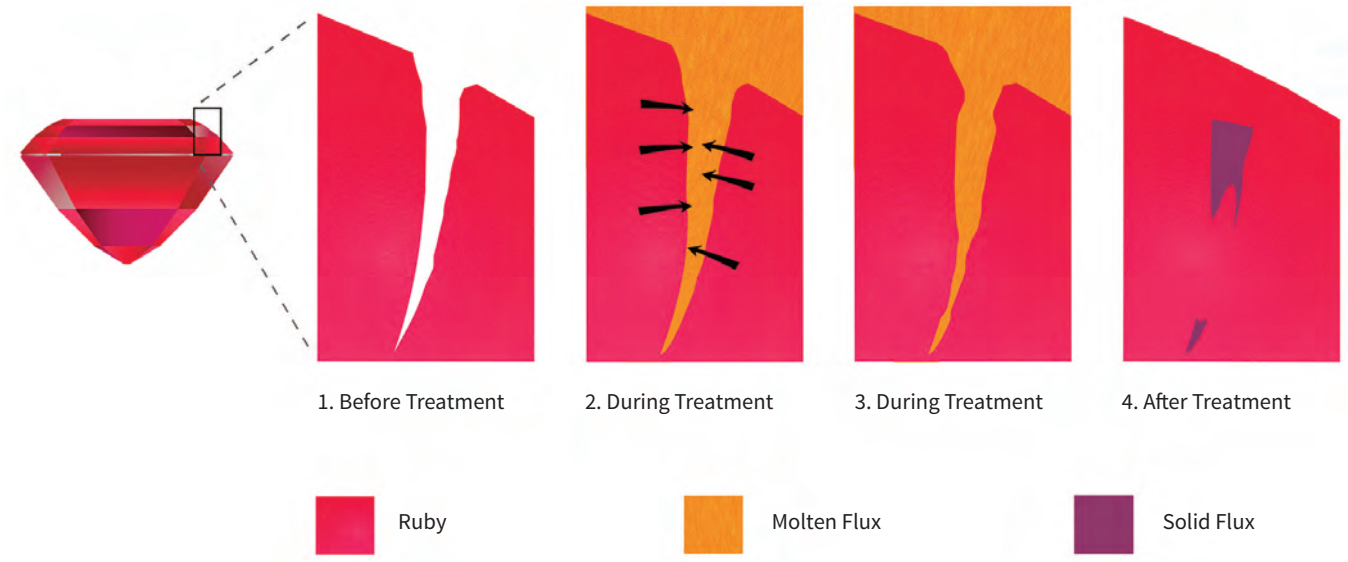
Heat can also eliminate, create, or alter the appearance of inclusions. High-temperature heating at 1250° to 1700°C (2282-3092°F) in the presence of a *flux* such as powdered borax, can partially heal surface-reaching fractures and growth tubes.

A flux is a solid material that, when melted, dissolves other materials in the same way that water dissolves sugar. Corundum is dissolved into the flux and deposited onto fracture walls as synthetic ruby, permanently sealing or healing the crack. The process also traps solid flux or flux residues that can't be removed by acid cleaning, so the treatment is stable.

This process is known as *flux healing* or flux-assisted healing. Corundum with partially healed fractures is just as durable as its unheated counterpart, and both typically require the same care and handling.

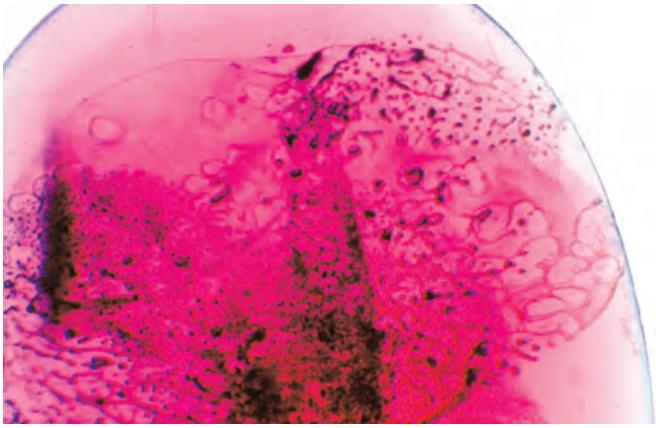
The line between heat treatment and flux healing got a little blurred in the 1990s. At that time, rubies from a source in Mong Hsu, Myanmar, were being heated to remove violetish cores from their centers, followed by higher temperatures to heal fissures and improve clarity.

Partially Healed Fractures



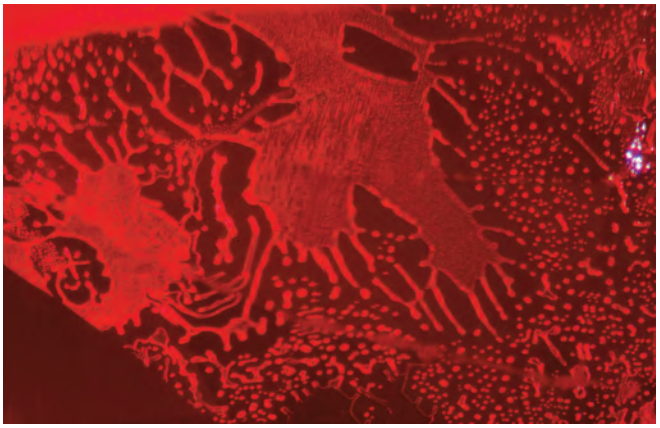
Peter Johnston/GIA

Heating at high temperatures in an environment with molten flux partially heals fractures, growth tubes, and other openings in a stone's surface (1). Corundum dissolves into the flux (2) and is deposited onto the fracture walls (3), permanently sealing or "healing" portions in some areas, making them invisible (4).



Duncan Pay

Some gem professionals believe that partially healed fractures are common in heat-treated Mong Hsu rubies. In the 1990s, disclosure of this treatment was one of the most important and controversial issues in the colored stone trade.

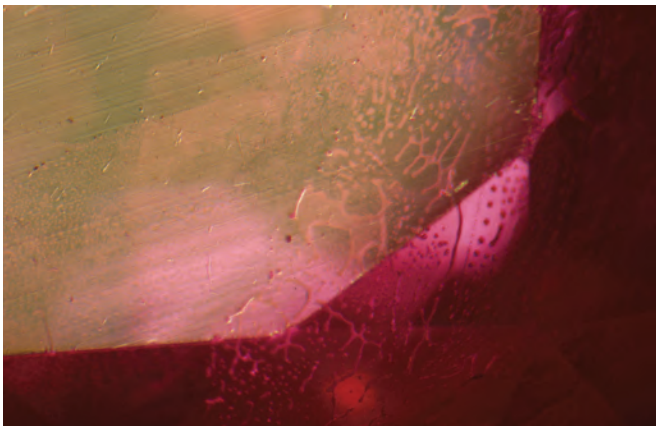


Shane McClure/GIA

In this partially healed fracture plane in a treated ruby, the darker areas are completely healed portions of the fracture. The frosted whitish areas are treatment residues trapped within the original fracture plane.

Shane McClure/GIA

Many rubies are heat-treated in the presence of a flux to partially heal fractures and improve clarity. The partially healed fractures commonly contain residues.

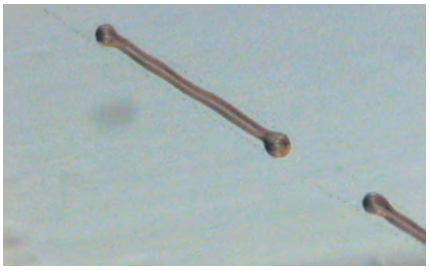


Shane McClure/GIA

The surface-reaching portion of a partially healed fracture is visible as a series of dots across this ruby's surface. There are also some silica glass residues from the fracture's unhealed portions.

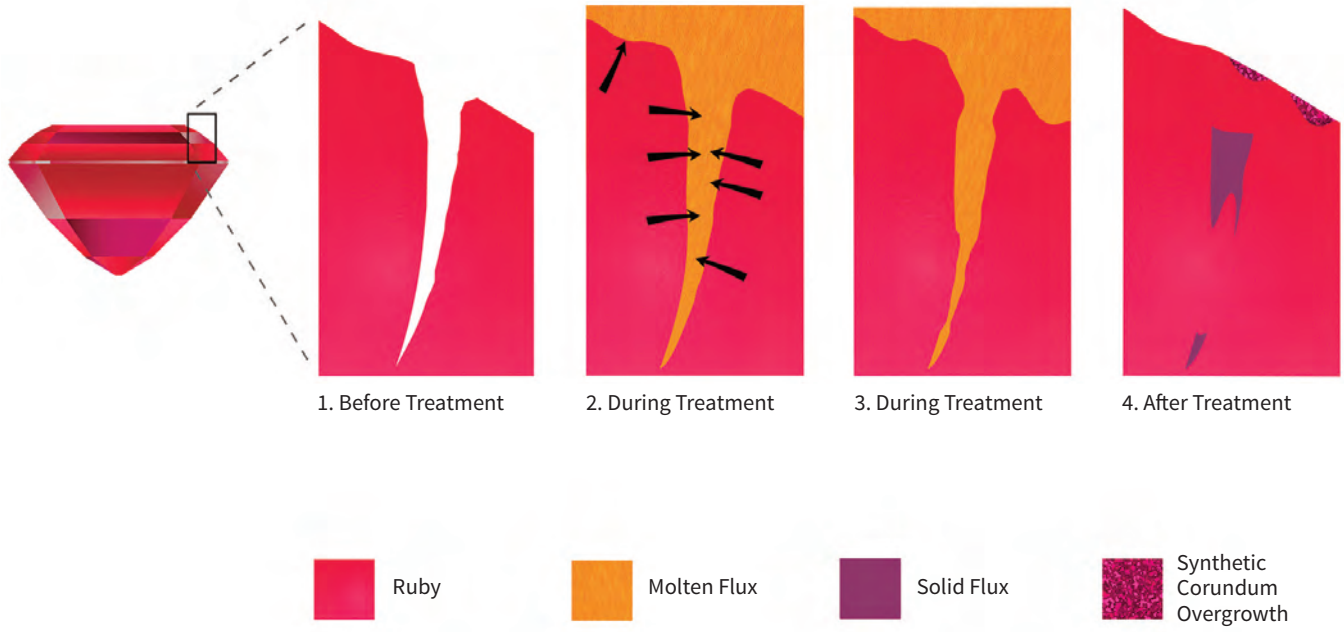
The gems were often packed in a borax powder or other flux material during treatment. Some people claimed this was done only to protect the rubies, but others said it was meant to improve clarity because the borax melted and then solidified in surface-reaching fractures. Either way, the end result was an improvement in the stone's face-up appearance.

This allowed reasonably priced Mong Hsu rubies to dominate the market at the time. Unfortunately, while heating was disclosed, the presence of the healed fissures was not. This caused controversy, led to reduced demand, and had a negative impact on public confidence in ruby. In addition, the treatment wasn't widely understood, and the presence of the flux led some gemologists to misinterpret the rubies as synthetic. Others confused the healed fissures with glass fillers.



This is a highly magnified portion of a partially healed fracture in a heated ruby. The "dumbbell" or "bone" shapes are residue. The gaps between them are completely healed areas of the fracture.

Heating with Synthetic Overgrowth



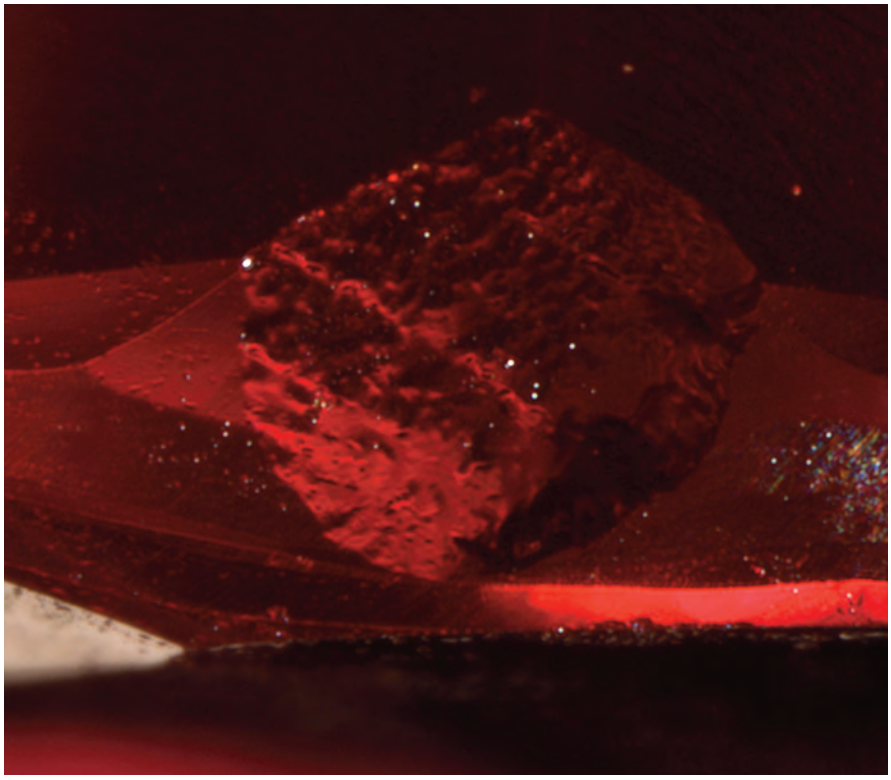
Peter Johnston/GIA

Heating at high temperatures in an environment with molten flux partially heals openings in a stone's surface such as fractures and growth tubes (1). During heating, the flux enters surface-reaching fractures in the gem (2), partially healing them (3). As the stone cools, synthetic corundum might be deposited by the flux and crystallize in cavities at the gem's surface (4).

Another possible effect of this treatment is the formation of synthetic corundum overgrowth. As the stone cools, synthetic corundum is deposited by the flux and crystallizes on the stone's surface, in cavities or around its girdle. Portions of this synthetic overgrowth layer sometimes remain on the stones after polishing.

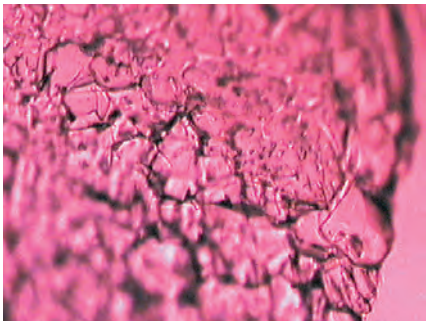
On lab reports, the disclosure comments for flux healing indicate heating and also declare the presence of any surface-reaching filled cavities or fissures. Depending on the extent of the healed fractures and the amount of residue present within the stone, the degree of treatment might be listed on the report as "minor," "moderate," or "significant."

In another use of heat and flux, treaters sometimes rapidly heat and cool flame-fusion synthetic rubies. This results in a pattern of small cracks that penetrate the gem. The stones are then treated at high temperatures with borax or other flux materials. This results in inclusions identical to the fingerprints seen in heated natural ruby. They're often referred to as "induced fingerprints."

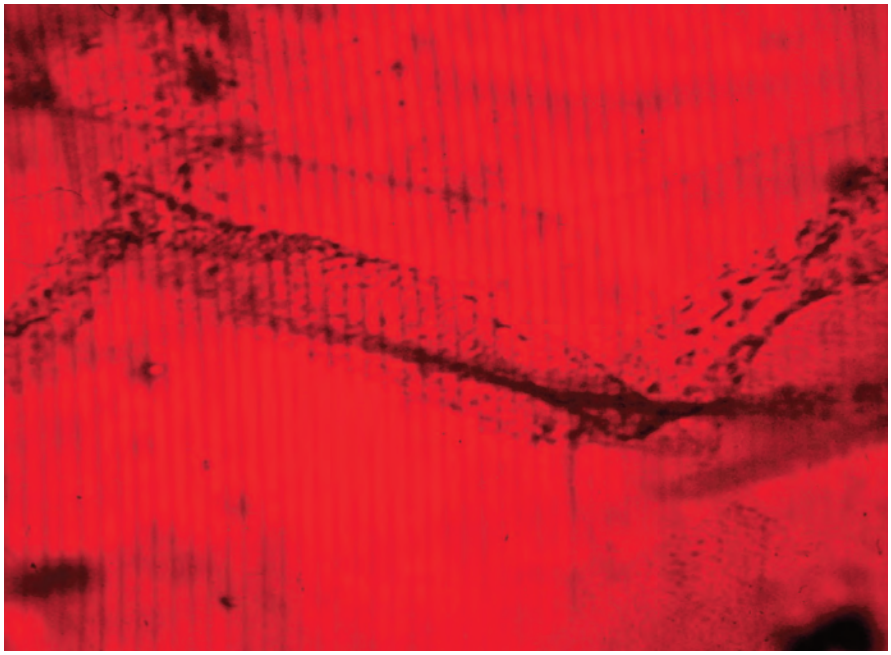


Nathan Renfro/GIA

This faceted ruby has an overgrowth of synthetic corundum on its surface. This can happen when rubies or sapphires are exposed to high temperatures, especially in the presence of a flux.

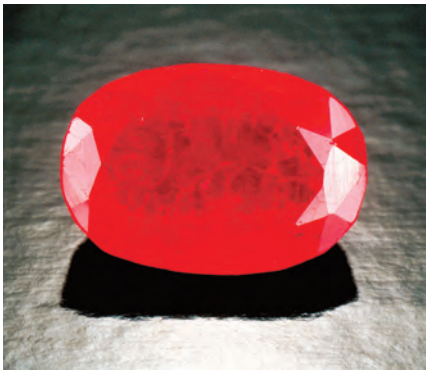


In this highly magnified view, a high-temperature treated ruby from Mong Hsu, Myanmar, shows a blocky intergrowth of synthetic corundum on its surface.



Karl Schmetzer

The borax in the fractures is often visible under magnification. Curved growth is typical of a flame-fusion synthetic.



Tino Hammid/GIA

Synthetic rubies are sometimes quench crackled and then exposed to high temperatures in the presence of borax. The borax penetrates the fractures and causes inclusions that give the stone a natural appearance.

Heat Treatment Resulting in Glass-filled Cavities

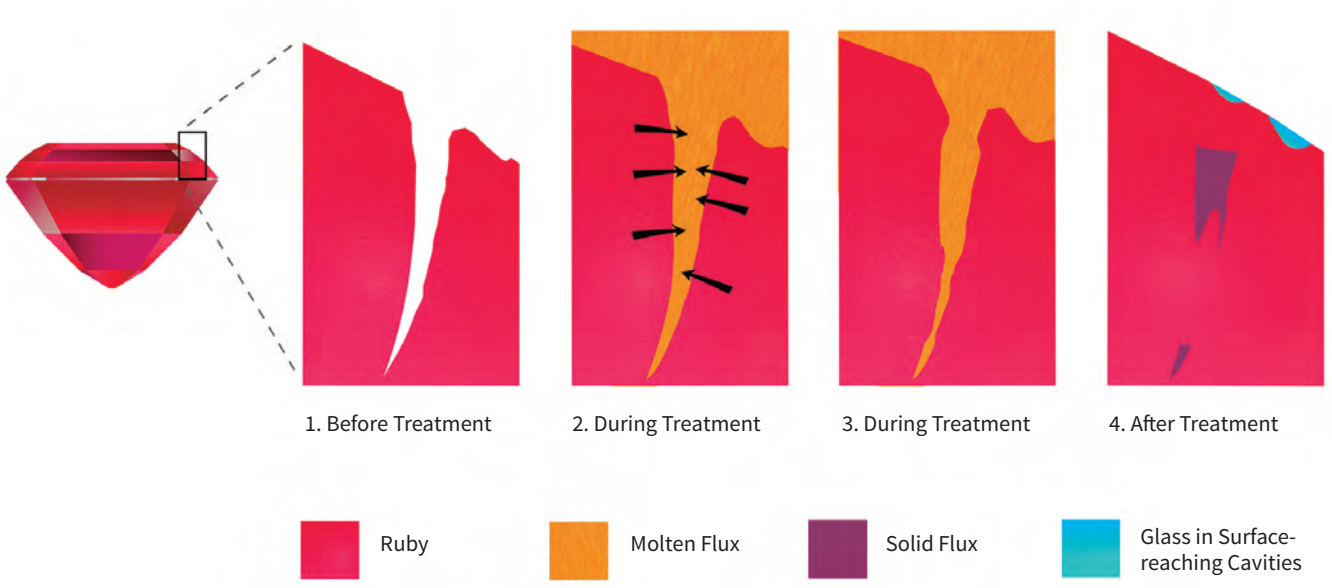
During heating in the presence of a flux, fissures or surface cavities that are too wide to be healed by recrystallized corundum might be filled with a material that is similar in composition to the glass residues trapped in partially healed fractures. Because they contain flux rather than recrystallized corundum, the fissures or cavities can be described as glass-filled.

Examination under a microscope can help detect the presence and amount of residue in healed fractures, or at the gemstone's surface. As glass is softer and more vulnerable to chemicals and heat than corundum, its presence can affect the stone's durability and appearance.

The glass in cavities can be removed professionally with a strong acid. Because they're narrower, removing glass from surface-reaching filled fractures is more difficult, and can dramatically alter the appearance of the stone and possibly affect its integrity, making it more vulnerable to cracking.

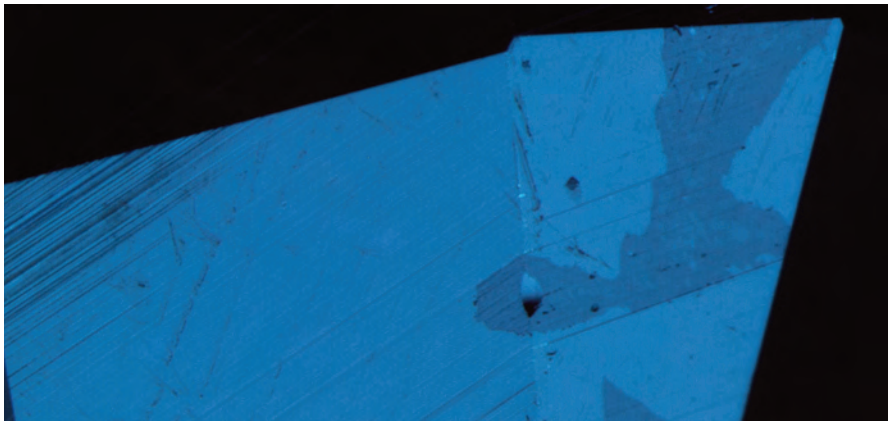
Depending on the extent of the glass-filled cavities present, the degree of treatment might be listed on a GIA report as "minor," "moderate," or "significant."

Glass-filled Cavity in Ruby



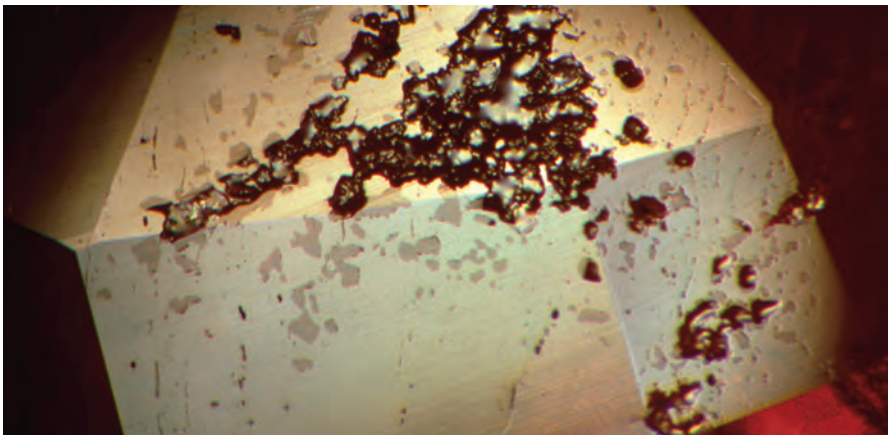
Peter Johnston/GIA

Heating at high temperatures in an environment with molten flux partially heals openings in a stone's surface such as fractures and growth tubes (1). During heating, the flux enters surface-reaching fractures in the gem (2), partially healing them (3). As the stone cools, flux in cavities at the gem's surface solidifies as glass (4).



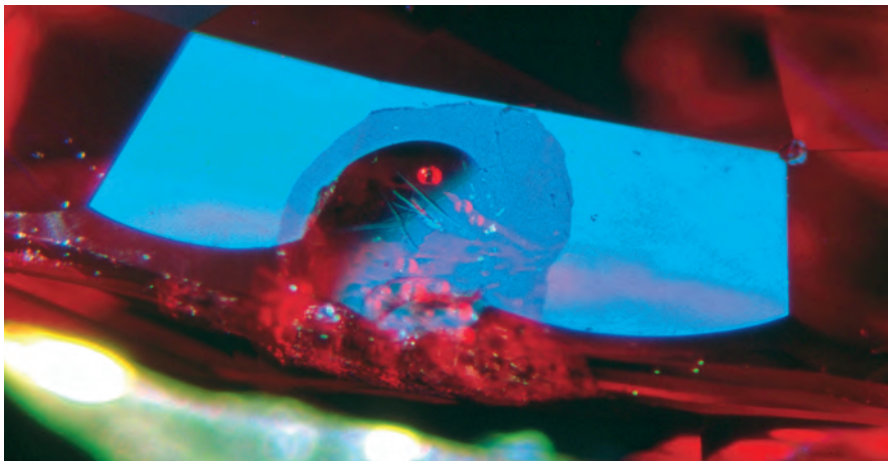
Nathan Renfro/GIA

The glass-filled cavities are visible in reflected light because their luster is lower than that of the host corundum.



Shane McClure/GIA

Some of the cavities in this gem were partially filled with glass. The luster of the smaller glass-filled cavities is visible in reflected light because of a luster difference between them and the host corundum.



Alan Jobbins & Ken Scarratt

It's easy to see the luster difference between the glass filling and the ruby. Some spherical gas bubbles within the filling are also clearly visible.

Robert Weldon/GIA

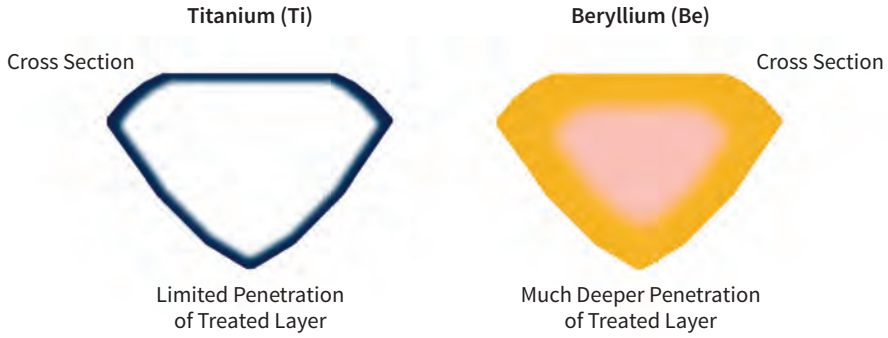
Most corundum colors can be affected in some way by beryllium diffusion treatment. These treated rough and faceted stones range in size from 1.03 to 8.53 cts.

Lattice Diffusion

Lattice diffusion—A treatment in which a gem is exposed to high temperatures and chemicals to allow penetration of color-causing elements.

Like some types of heat treatment, *lattice diffusion* involves high temperatures. Unlike most heat treatments, however, the temperatures are so extreme that they're close to the melting points of the stones being treated. With corundum, the very high temperatures—above 1700°C (3092°F)—allow color-causing elements like iron, titanium, chromium, and beryllium to penetrate the gem's crystal lattice to varying degrees.

At first, gemologists used the term "surface diffusion" to describe this treatment because the heavier elements used—like chromium and titanium—only penetrated a short distance into the gem's crystal lattice and produced only a thin layer of color at its surface. When treaters began using beryllium—a much lighter element that penetrated more deeply into the gem's crystal lattice, coloring it all the way through—they called the process "bulk diffusion." Today, gemologists simply use "lattice diffusion" to describe all diffusion treatments.



Peter Johnston/GIA

Chemical elements along with heat can add color to pale starting material. Titanium lattice diffusion produces dark blue near-surface coloration with limited penetration into the stone (left). Treatment gives colorless or light blue material a much darker color. Lattice diffusion with beryllium (right) can penetrate much more deeply into the corundum, sometimes all the way through. In this example, treatment with beryllium penetrated much more deeply into pale pink sapphire, producing an artificial pinkish orange or "padparadscha" color.

Corundum isn't the only material treated with lattice diffusion. Large volumes of red and green feldspar treated by lattice diffusion with copper entered the market in the early to mid-2000s. The treatment was initially not disclosed, so traders and consumers alike responded very negatively once they became aware of the material's artificial color.

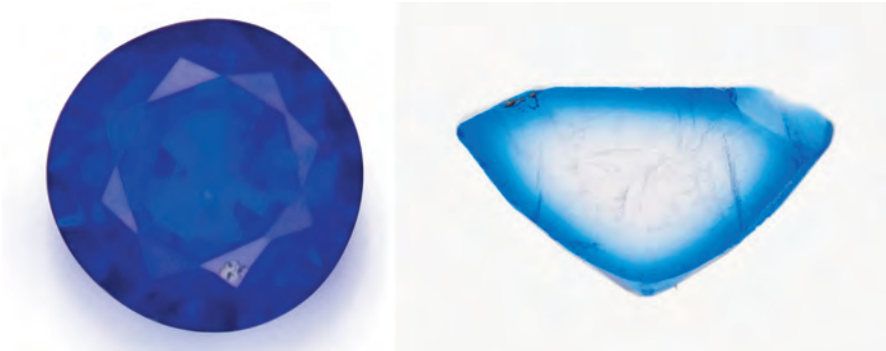
The deception resulted in a threat to the market for naturally colored red feldspar, principally "sunstone" labradorite from the US state of Oregon. This motivated miners and suppliers of Oregon sunstone to promote the natural, untreated status of their gem. This resulted in a significant improvement in the market for their product by 2015.

KEY CONCEPTS

Quantities of lattice-diffusion treated corundum, feldspar, and spinel had entered the gem market by 2015.

Robert Weldon/GIA

Large quantities of attractive feldspars entered the market in the mid-2000s. Said to be from locations including Mongolia, Congo, and Tibet, many turned out to owe their attractive colors to copper diffusion treatment. These fashioned gems were represented as untreated andesine feldspar from Tibet. They weigh 0.45 to 15.51 cts.



The faceted cobalt-diffused spinel and the polished slice from another sample reveal the surface penetration of blue color produced by the treatment.

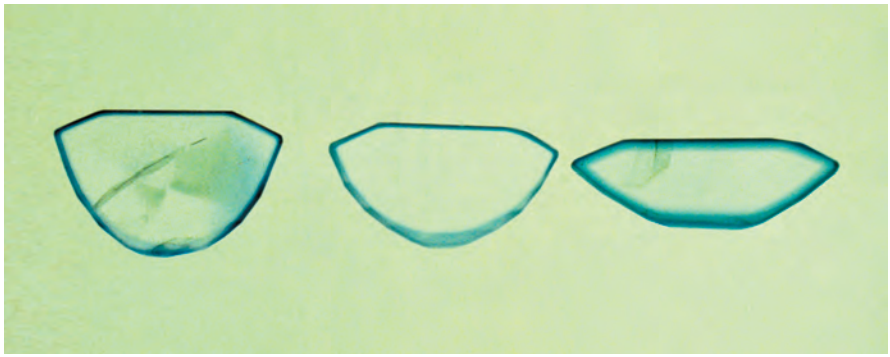
In 2015, several gem laboratories identified blue spinel that had been treated by lattice diffusion with iron and cobalt. In response, the Thai company responsible for these treated gems provided GIA with samples. When lab professionals cut some of them into slices for analysis, they noted that the blue color was confined to the outer surface. Magnification revealed altered inclusions that indicated exposure to high temperatures. Further analysis confirmed that the concentration of cobalt at the stone's outer rim was many times greater than at its center.

Corundum Lattice Diffusion with Heavier Elements

Lattice diffusion can be used with colorless or very light-colored natural corundum, especially sapphire that doesn't respond to normal heat treatment. Treaters place faceted corundum in a crucible containing a coloring agent like titanium or chromium. They then set the packed crucible in a furnace that's heated to temperatures approaching corundum's melting point. The length of treatment and the surrounding environment vary depending on the desired result.

Shane McClure/GIA, courtesy Gem Source

Lattice diffusion treatment with titanium is sometimes used on pale corundum that does not respond to heat treatment. The treatment deepened the blue color of the center stone, but the high temperatures created burned areas on its surface. After treatment, the stone on the right was repolished to remove the burned areas and make the stone marketable.

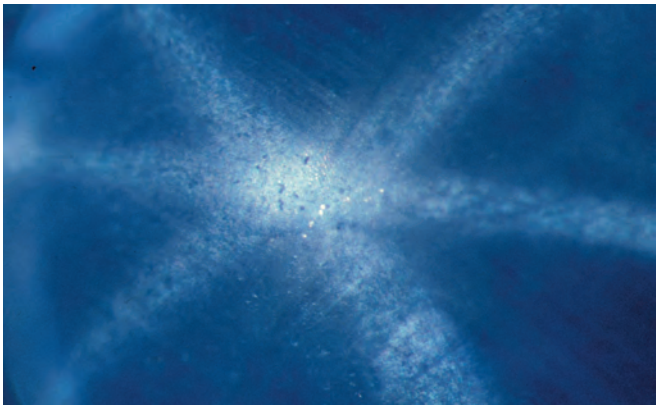


Shane McClure/GIA

Cross sections of sapphires treated by lattice diffusion with titanium show that the color penetration layer is very shallow.

Maha Tannous/GIA

Asterism can be created in corundum by diffusing a shallow layer of titanium oxide below the stone's surface. Several days of heating at high temperatures then crystallizes the titanium oxide into rutile needles. The result is a shallow star.



John Koivula/GIA

Magnification reveals that the very fine intersecting rutile needles in the titanium-diffused corundum are confined to a layer just below the surface.

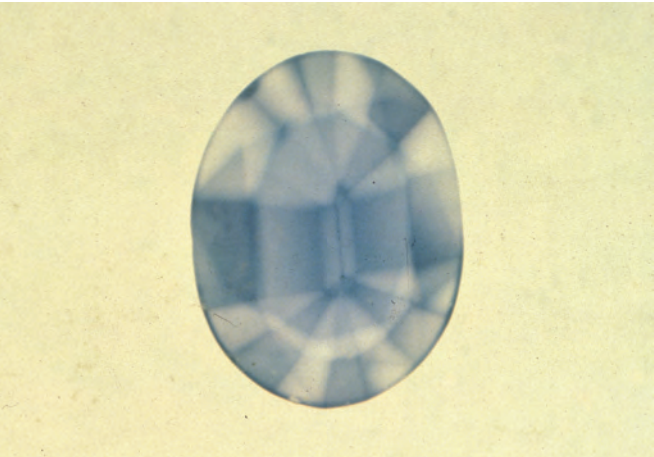
For decades, treaters diffused corundum with iron and titanium oxides to create blue stones, and with chromium to create red stones. Lattice diffusion with titanium or chromium typically produces a thin layer of color at or just below the stone's surface. The layer is only 0.01 mm to 0.50 mm deep, depending on the element being diffused and the temperature and duration of heating. Repolishing the gem to remove burned areas can totally or partially remove the shallow color layer.

Lattice diffusion can also create a shallow layer of asterism in corundum. Titanium oxide is introduced into a cabochon that's heated to about 1300°C (2370°F). After heating, the corundum is cooled slowly over several days. This allows the titanium oxide to crystallize into rutile needles. The result is almost always a beautiful star.

The most effective way to detect lattice diffusion is to immerse corundum in a liquid, such as methylene iodide, that reduces surface reflections. This makes it easier to see the gem's color distribution and the characteristic signs of treatment. For lattice diffusion with titanium or chromium, these

KEY CONCEPTS

Lattice diffusion with heavier elements like titanium and chromium produces a shallow layer of color that might be removed by minor repolishing.



Shane McClure/GIA

Immersion often reveals patchy surface coloration in titanium-diffused sapphires. This is because some of the shallow treated layer is removed during polishing. This is not seen in beryllium-diffused corundum because the treated layer is much thicker.

Elizabeth Schrader/GIA

Lattice diffusion with beryllium results in a variety of desirable sapphire colors, including yellows, oranges, reds, and orangy reds.

Kevin Schumacher/GIA

Lattice diffusion with beryllium can result in attractive pink or orangy pink sapphire colors. These stones range in size from 0.51 ct. to 0.84 ct.

Kevin Schumacher/GIA

The same group of beryllium-diffused sapphires reveals the depth of their treated layers when immersed table-down in liquid.

include concentrated color along facet junctions and around the girdle, localized color caused by uneven diffusion of color-causing elements, and color that's missing from some facets.

Corundum Lattice Diffusion with Lighter Elements

Beryllium diffusion is a newer corundum treatment that results in a wide range of colors, including yellow, red, and blue. In the early 2000s, treaters used beryllium diffusion to give pink sapphire from Madagascar a pinkish orange color, similar to rare, natural "padparadscha" sapphires. Treaters initially represented the technique as standard heat treatment. When its true nature was revealed, there was a backlash against all treated corundum. This hurt sales, but also increased demand for untreated stones.

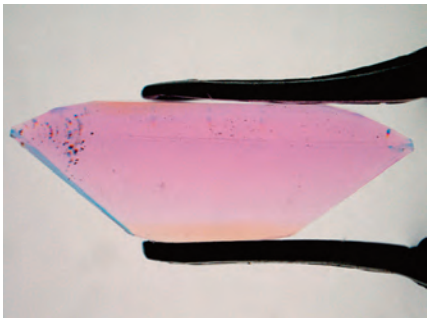
Beryllium diffusion was later used to affect many other corundum colors. A combination of heat treatment and beryllium diffusion can reduce the impact of dark zoning and improve the color of blue sapphires from locations like China, Vietnam, Australia, and Nigeria.

Beryllium diffusion in an oxidizing environment removes or lightens most of the blue color, but causes a small amount of yellow to appear. Subsequent standard heat treatment in a reducing environment removes the yellow color and slightly increases the saturation of the blue. The process has restored the profitability of some mining operations, like those in Chanthaburi, Thailand, since it makes previously unmarketable stones available for sale.

Sometimes, successful treatments are discovered by accident. Researchers assume that beryllium lattice diffusion of corundum was one of those. Frequently, chrysoberyl—which contains beryllium—is found in the same mining areas as corundum, and might have been mixed in with some parcels. When heating released the chrysoberyl's beryllium, it permeated the corundum. This encouraged treaters to develop more reliable sources of beryllium, such as beryllium oxide, for better control.

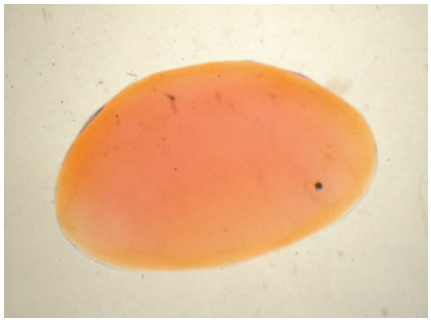
KEY CONCEPTS

A combination of beryllium diffusion and heat treatment can improve color in some dark blue sapphires and make them more marketable.

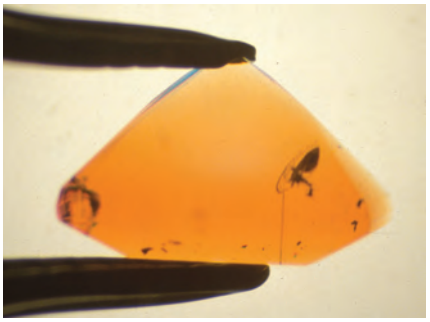


Nathan Renfro/GIA

Immersion reveals orange color zones along the culet and table of this pink sapphire. These were caused by beryllium diffusion treatment.

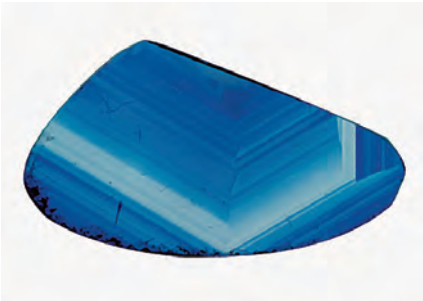


Beryllium diffusion can penetrate a ruby or sapphire to any depth, including all the way through. The depth is directly related to the length of time the stone was being treated.

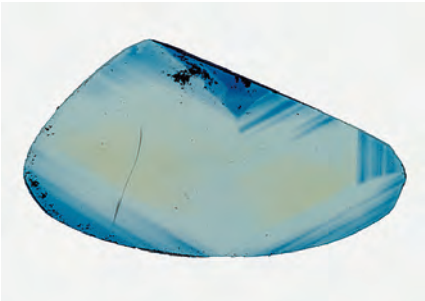


Shane McClure/GIA

Long-term beryllium diffusion can result in total penetration of the induced color layer.



John Emmett



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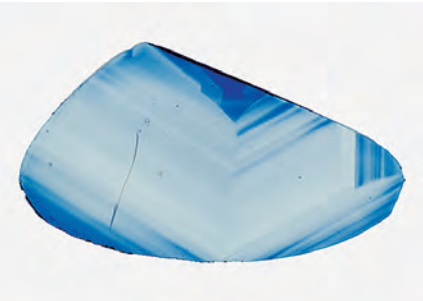
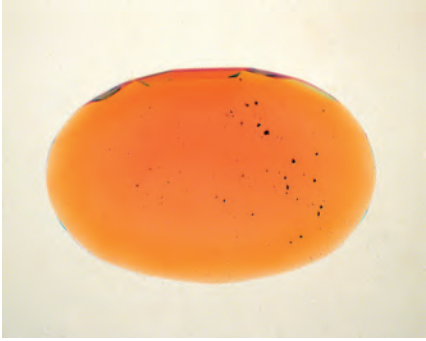


John Emmett

As part of a beryllium diffusion experiment, this thin wafer was cut from an extremely dark blue basalt-type sapphire from Shandong, China. Before treatment, the gem displayed very strong color zoning (left). After beryllium diffusion in an oxidizing atmosphere, most of the blue color was removed or greatly lightened, but a small amount of yellow color appeared (center). Subsequent standard oxygen-reducing heat treatment removed the yellow color and slightly increased the saturation of the blue (right). The experiment demonstrated the potential of treatment to make this material more marketable, but it isn't clear if it's practical on a commercial scale.

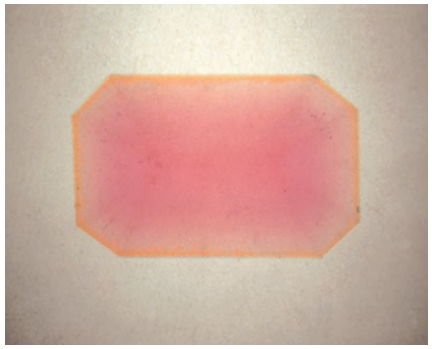
Shane McClure/GIA

After repolishing, lattice diffusion treated corundum might show uneven color distribution on its facets.



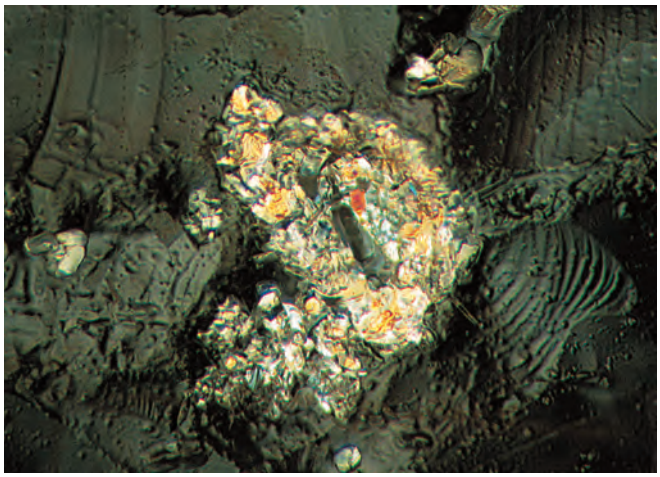
Shane McClure/GIA

A combination of magnification and immersion helps you see the surface-related color zoning that's characteristic of sapphires treated with lattice diffusion.



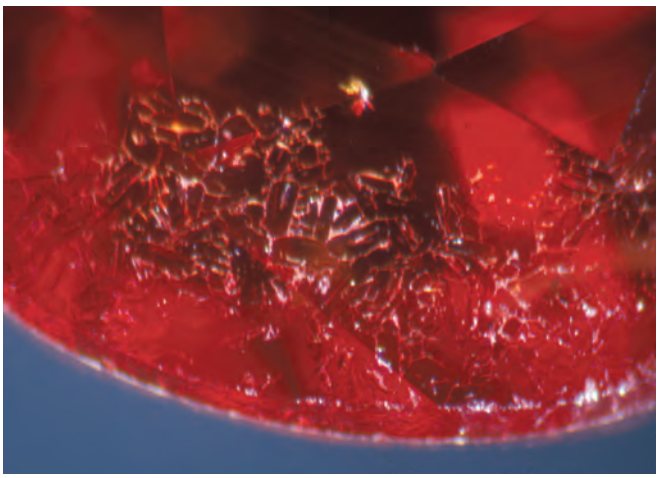
Shane McClure/GIA

Pink-orange beryllium-diffused stones generally show distinct yellow-to-orange surface-related zoning under magnification and immersion.



Shane McClure/GIA

The high temperatures required for lattice diffusion often result in a deposit of synthetic corundum on a treated gem's surface.



Because the high temperatures required for beryllium diffusion treatment are close to the melting point of corundum, synthetic overgrowth can occur on the surfaces of treated stones. The blocky appearance of this ruby's surface crystals is characteristic.

KEY CONCEPTS

The color resulting from lattice diffusion with beryllium can penetrate the entire stone.

The color layer induced by lattice diffusion with beryllium can be thick enough to penetrate the entire stone. This is due to the combined effect of the beryllium ion's valence charge and its much smaller radius compared with the aluminum ions in corundum's structure. This allows relatively small concentrations of beryllium ions to migrate easily through the crystal lattice. Because it can diffuse deeply into a stone, the color it induces is often very even compared to the shallow, patchy color from titanium diffusion. Also, repolishing typically won't remove the beryllium-diffused color.

Advanced testing might be needed to identify beryllium-diffused corundum. Signs include an orange rim surrounding a pink core. A treated gem might also have an overgrowth layer of synthetic corundum and highly altered zircon inclusions.

Temperature Ranges and Goals of Important Corundum Treatments

Heating Levels	Approximate Temperatures	Environments and Special Conditions	Treatment Goals
Low temperatures	Below 800°C (<1470°F)	Air (for example, through a blowpipe) for short durations	Color improvement: Removes blue color zones in ruby (makes purplish stones redder); very subtle changes to inclusions
Moderate temperatures	800°C to 1250°C (1470-2282°F)	Oxidizing (causes trace elements to lose electrons)	Color improvement: Removes blue color zones in ruby (makes purplish stones redder); many rubies from Mong Hsu, Myanmar, Vietnam and Mozambique treated this way; significant alteration of some inclusions
High temperatures	1250°C to 1700°C (2282-3092°F)	Reducing (causes trace elements to gain electrons)	Color improvement: Development of blue in pale, low-iron stones containing rutile particles or silk, including Sri Lankan geuda sapphires as well as Madagascar and Kashmir sapphires; pale, silky stones become deep blue; improvement of stones treated in the 1980s.
		Oxidizing (causes trace elements to lose electrons)	Color improvement: Development of strong yellow in white or pale yellow low-iron stones, especially Sri Lankan sapphires
		High temperatures followed by rapid cooling to about 1250°C (2282°F), followed by further controlled cooling	Clarity improvement: Removes rutile silk in cloudy material; improves transparency; improves many dark blue basaltic sapphires
		Presence of a flux agent such as borax	Clarity improvement: Heals natural fissures in presence of a flux; makes fractures/fissures less visible, strengthens stone by closing fractures
Extreme temperatures	Above 1700°C (>3092°F)	Packed in a slurry of metal oxides (titanium, iron for blue; chromium for red to pink)	Color improvement: Development of artificial blue or red color by diffusion. Light or near-colorless gems develop surface-related blue (titanium-iron) or red (chromium) color zones that conform to the polished gem's outline and are often partially removed by polishing.
		Heated with source of beryllium in an oxidizing environment	Color improvement: Development of artificial color by diffusion. Converts pale pink stones to "padparadscha"-type colors. Converts strongly purplish or brownish red stones to ruby colors. Can also create yellow or orange colors. Surface-conforming color zone much deeper than titanium or chromium, and might penetrate entire stone.
		Heated with source of beryllium followed by conventional high-temperature treatment in a reducing environment.	Color improvement: Removal of blue color by diffusion. Lessens or removes strong dark blue color zones in basaltic sapphire. Adds artificial yellow or orange color, which can be removed by subsequent heating.
		Packed in a slurry of metal (titanium) oxide. Controlled cooling to precipitate rutile needles.	Phenomenon development: Creation of artificial star by diffusion. Stones with absent or weak asterism develop a surface-related star.

KEY CONCEPTS

Fracture filling is the most common form of clarity enhancement.

Clarity enhancement—Treatment that improves the apparent clarity of a gem with a colorless or near-colorless filler.

Fracture (fissure) filling—Use of a colorless to near-colorless filler to conceal fractures and improve the apparent clarity of a gem.

Clarity Enhancement

Clarity enhancement is the practice of filling surface-reaching fractures or fissures with a variety of colorless to near-colorless substances. Many gems are treated this way, including emerald, ruby, tourmaline, tanzanite, topaz, and beryl. The most common form of clarity enhancement is called *fracture*, or *fissure*, *filling*. The trade often refers to it simply as "filling."

The treatment consists of filling tight, narrow fractures in a gem with a substance that has a refractive index (RI) close to that of the gem. This causes the light to pass through the filled fracture in much the same way as it passes through the surrounding gem. Besides making the fracture much less visible, the treatment improves the gem's transparency as well as its color and overall appearance. Although clarity enhancement is relatively common, it's not stable, so the stone's appearance can change over time. Many different substances can be used for this purpose. If the treatment uses lead glass, this is typically noted on a laboratory report.

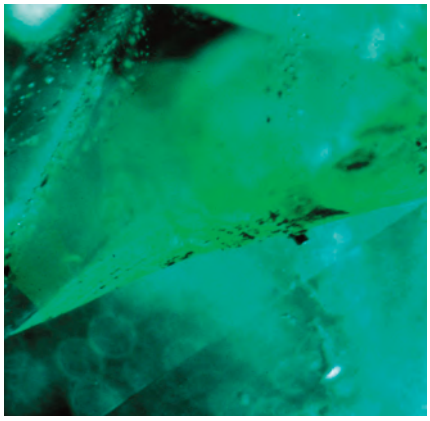
Tino Hammid/GIA

Tino Hammid/GIA

The use of oils, resins, and polymers to fill emerald fractures can have dramatic results. This untreated stone (top)would be difficult to sell even at a low price. Fracture filling improved its apparent clarity and color, making it much more presentable (bottom).

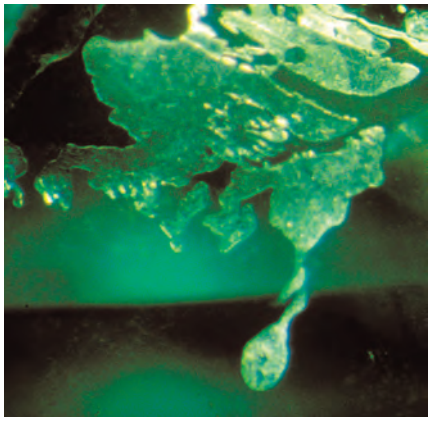
Harold & Erica Van Pelt/GIA

Emerald, the premier green colored stone, would be extremely scarce in attractive qualities if it weren't for the widespread use of fracture filling.



Robert Kane/GIA

Filling a fracture in beryl with colored oil is considered both fracture filling and dyeing. The treatment conceals fractures and gives the stone a green or deeper green color.



John Koivula/GIA

Irregularly shaped gas bubbles trapped in the filling material are evidence that this emerald was fracture-filled.

KEY CONCEPTS

Today, almost all emeralds on the market are subjected to clarity enhancement.

Resin—A clear, viscous substance that's used to fill fractures in gemstones.

Polymer—A liquid filling material that's very durable when it dries.

Hardener—A chemical that treaters mix with some resins to cause them to solidify.

When the fractures are wider and more extensive, the filler can add durability, even allowing the fashioning of highly fractured rough that might otherwise break during the cutting process.

Modern fillers include colorless oils in corundum and emerald, synthetic *resins* and *polymers* in emerald, and various glass types in corundum. Sometimes, treaters add a *hardener* to resin fillers to solidify them and make the treatment more durable. Polymers are very durable when they dry.

The fillers must have an RI that is close to that of the treated gem material. This causes the light to pass through it in much the same way as it passes through the surrounding gem, making the filler and the filled fracture much less visible.

As you've learned, emeralds commonly contain fractures. Mining, fashioning, jewelry manufacturing, and gem setting can all cause further damage. For this reason, most emeralds need some type of filling to be salable. Without it, the supply of attractive, desirable emeralds would be a fraction of what it is today, and the few emeralds available would be extremely expensive. However, there is no agreement in the trade about which filling substances are most acceptable.

The use of oil to fill fractures in emerald is a centuries-old practice that's still common despite concerns about durability. There are a couple of reasons for this. First, the treatment doesn't require expensive equipment. Second, there are many more buyers who expect excellent color and clarity than there are high-quality untreated emeralds.

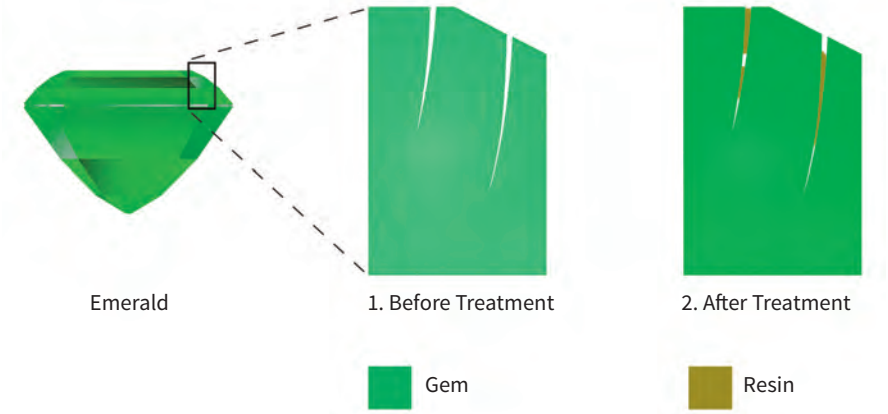
The fillers used include Canada balsam, manmade resins, and cedarwood and palm oils. Each type has its advantages and disadvantages, and there's little agreement in the trade about which is best. However, there's general agreement that most emeralds require fillers to be saleable.

Tino Hammid/GIA

Tino Hammid/GIA

Today, most emeralds in the market are treated. Untreated emeralds commonly have whitish fractures that distract from their appearance (top). Treaters use a variety of substances to fill fractures and make them less visible (bottom).

Emerald with Resin



Peter Johnston/GIA

When an emerald has tight fractures that don't threaten the stone's durability (1), treaters can induce a filler into the fractures. The treatment helps to increase the gem's transparency and improve its color and overall appearance (2). However, the treatment is not stable and the stone's appearance can change over time.

Routine cleaning and jewelry manufacturing procedures can affect the materials used to fill emerald fractures. Oiling is usually repairable: An emerald's appearance can be restored if oil is accidentally removed, or if it becomes discolored. This is less certain with resins, which vary in their ease of renewal and replacement, long-term durability, and fracture-concealing properties. When they first came into widespread use in the early 1990s, some attempts to remove them were unsuccessful. Today, some manufacturers guarantee that they can remove the resins and re-treat the stones.

No matter what their content, most fillers are colorless or nearly colorless. If a dye is added to the filler to enhance the gem's color, the treatment should be disclosed as both dyeing and clarity enhancement.

Maha Tannous and Tino Hammid/GIA

Fracture filling is a common emerald treatment, but it might also be used for other gems. The fractures in this untreated aquamarine are highly visible.

Maha Tannous & Tino Hammid/GIA

After fracture filling, the fractures in the same aquamarine are almost invisible and the gem is much more marketable.

Glass Filling of Corundum

By the mid-2000s, lead-glass filling of lightly fractured ruby from Madagascar—and later from Mozambique—was having a significant impact on the ruby market. Lower-quality material was also being fracture-filled with high-lead content glass, making worthless material marketable.

The first step in the treatment is to clean the ruby with acid to remove any staining or mineral deposits. Glass filling of fractures in corundum requires temperatures of 600° to 1400°C (1112-2552°F), depending on the melting point of the glass being used. The RI of lead glass is closer to that of corundum than oil or other glass types. It also has a low melting point of approximately 700°C (1292°F), so it doesn't require high heat to become fluid enough to penetrate the stone under vacuum pressure.

C. D. Mengason/GIA

The starting material for glass filling is lower-quality ruby rough, typically from Madagascar or Mozambique.

Elizabeth Schrader/GIA

These stones—weighing 2.15 to 7.42 cts.—are typical of the result achieved with the filling of ruby fractures with high-lead glass.

Shane McClure/GIA

Lead glass was induced into tight fractures in this 7.22-ct. ruby, making them less visible.

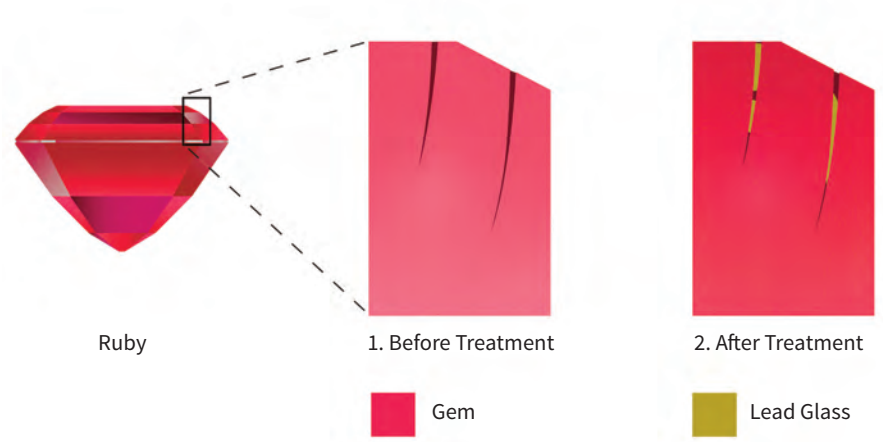
Vincent Pardieu/GIA

Treaters can use lead-glass filling to enhance the appearance of star ruby. The low temperatures required for glass treatment do not affect the rutile needle inclusions responsible for the material's asterism.

Robert Weldon/GIA

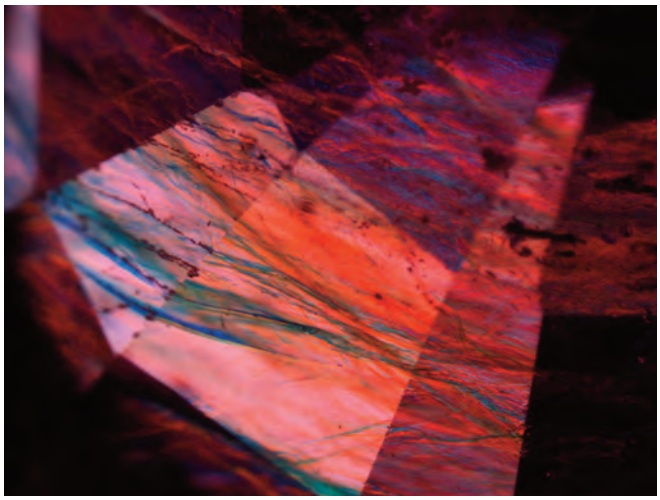
Synthetics are also sometimes treated, so the presence of treatment should not be taken as evidence of natural origin. This 3.50-ct. flame-fusion synthetic ruby contains many glass-filled surface-reaching cracks.

Ruby with Lead Glass



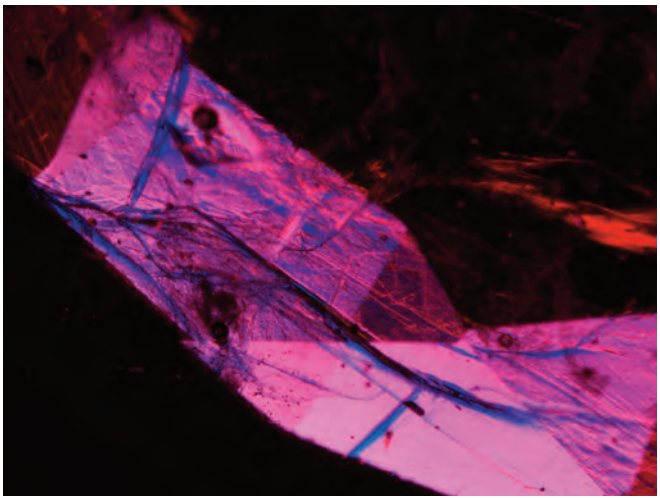
Peter Johnston/GIA

Starting with corundum whose tight fractures don't threaten the stone's durability (1), lead-content glass is induced into the fractures. The glass helps to increase transparency and improve the gem's color and overall appearance (2). The treatment, however, is not stable and the stone's appearance can change over time.



Nathan Renfro/GIA

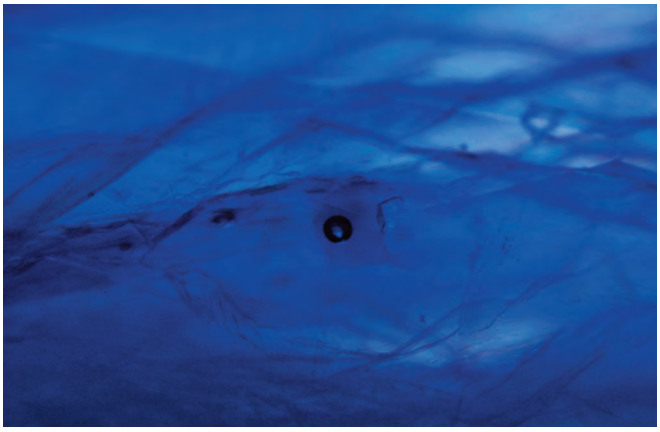
With darkfield illumination and magnification, lead-glass filled ruby might show an orange and blue flash effect as the observer rocks and tilts the stone.



Shane McClure/GIA

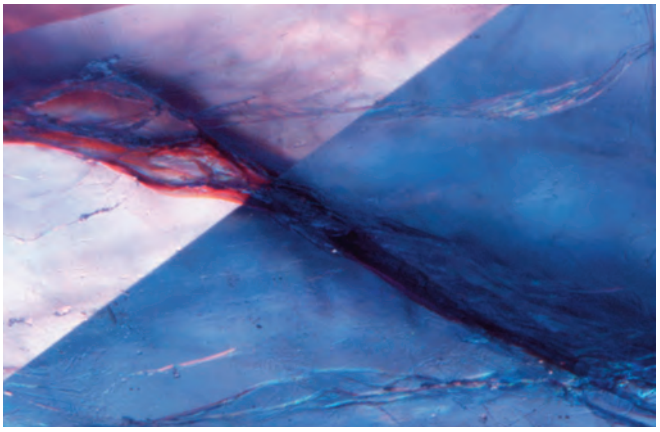
A blue flash effect is evident in this lead-glass filled ruby. This is due to the difference in RI between the filler and the host ruby.

The disadvantage is that lead glass is much softer than corundum. This results in an uneven wear pattern, where the surface-reaching filler shows scratches while the surrounding ruby retains its polish. Pale, low-quality corundum might also be filled with lead glass that contains cobalt, giving the corundum an attractive vivid blue color. Blue color concentrations in the fractures, gas bubbles trapped in the filler, and the presence of cobalt, which is not a natural corundum coloring agent, are all readily detected by standard gemological testing.



Nathan Renfro/GIA

Cobalt glass can be used to fill voids, channels, and fissures in highly fractured light or near-colorless corundum. This produces the appearance of a much more strongly colored material. The gas bubble that's clearly visible within the filler is key evidence of this type of clarity enhancement.

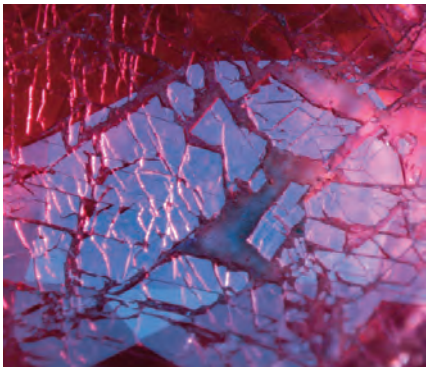


Nathan Renfro/GIA

Due to differences in RI between the cobalt-glass filler and the corundum, you can sometimes observe a flash effect in darkfield lighting.

Nathan Renfro/GIA

The network of glass-filled fractures holding this stone together is clearly visible under reflected light.



Nathan Renfro/GIA

The recessed areas on the surface of this heavily fractured ruby with extensive glass filling are places where the filler was etched away by chemicals or a jewelry repair process. This shows that the material can be damaged by routine procedures that wouldn't damage other natural and treated corundum.

Because of its low melting point, lead-glass filler can be damaged or removed if the stone is left in the setting during a jewelry repair. Treated gems require caution with hydrofluoric and other acids, heat from a jeweler's torch, and chemicals such as caustic soda. It's important to avoid these materials and conditions and not to subject treated stones to ultrasonic or steam cleaning. Because of its special care requirements, the use of lead glass must be part of the clarity enhancement disclosure.

KEY CONCEPTS

Filling with glass or resin can stabilize highly fractured, otherwise unusable rough so it can be processed for jewelry use.

The proportion of filler in some lead-glass treated gems is so high that gem labs consider them composites or manufactured products.

Manufactured and Composite Materials

Along with roughly shaped or faceted material, treaters also began using glass or resin to treat good-color rough that was too fractured for jewelry use. Starting with corundum or emerald rough with extensive fractures, twinning, or voids, they inject the filler into the openings. The filler connects the fracture walls and makes them less visible. The purpose is to make the rough strong enough for fashioning and allow the fashioning of larger gems than would otherwise be possible.

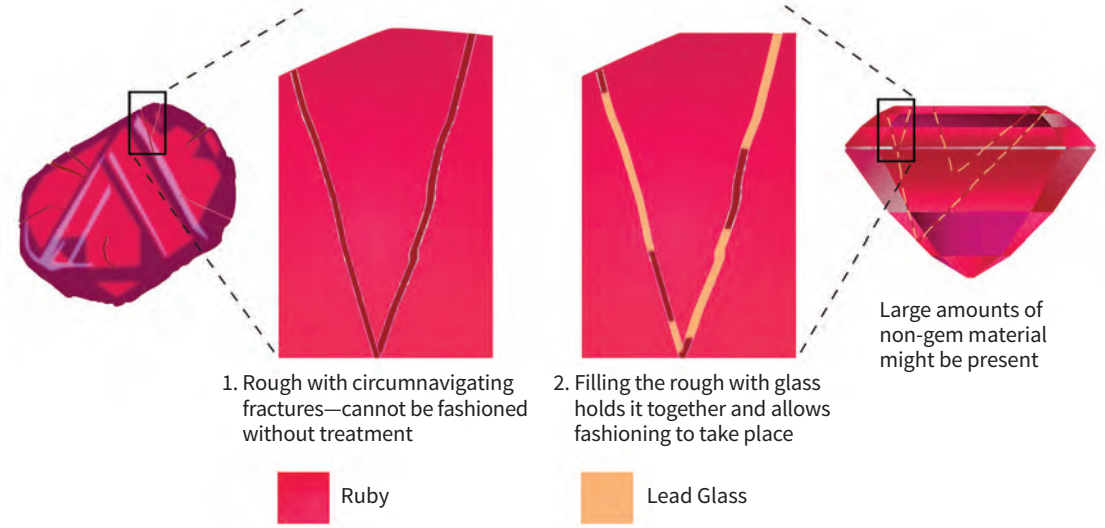
Sometimes, the filler is so extensive that it becomes a significant component of the finished product. The result, which often can no longer be described as a gem, is described as a "composite" or "manufactured material."

With ruby, the first step is to use acid to remove minerals and staining from the fracture. Then the material is infused with lead glass in a pressurized or vacuum environment to prepare it for cutting and polishing.

The result is a dramatic improvement in clarity, but because the treatment introduces a significant amount of lead glass, even whole facets might end up being composed of glass. The higher density of the lead-glass filler in those cases can cause an increase in the stone's specific gravity.

In newly treated stones, filled fissures and cavities can be indistinguishable from the surrounding ruby, but wear and exposure to household chemicals can change the appearance of the lead glass. Once the stone is faceted, the treated areas might occupy the entire finished stone. Removing the filler would cause the stone to fall apart. The cost of this product, which can be found in large sizes, is usually less than $10 per carat.

Ruby with Lead Glass



Peter Johnston/GIA

Starting with rough corundum that has extensive fractures throughout the stone, glass is induced into its open fractures. This causes the walls of the fractures to adhere and the fractures to become less visible. Once the stone is faceted, these fractures penetrate the entire finished stone. If the glass were removed the faceted stone would fall apart.

Irradiation

Irradiation involves bombarding a gemstone with electromagnetic radiation (X-rays or gamma rays) or subatomic particles (neutrons or electrons) to change its color. It's used to treat a wide variety of gems. Irradiation often creates color centers that are responsible for the resulting treated color. The color centers aren't always permanent. Exposure to heat or light can destroy them and remove the color.

Irradiated blue topaz made a big impact on the market in the 1980s. Almost any colorless or light yellow topaz can be turned brown by high-energy electron or neutron bombardment. The color is not stable to light or heat, but it can be converted to a stable blue by controlled heating (called annealing) of the stone for just a few hours.

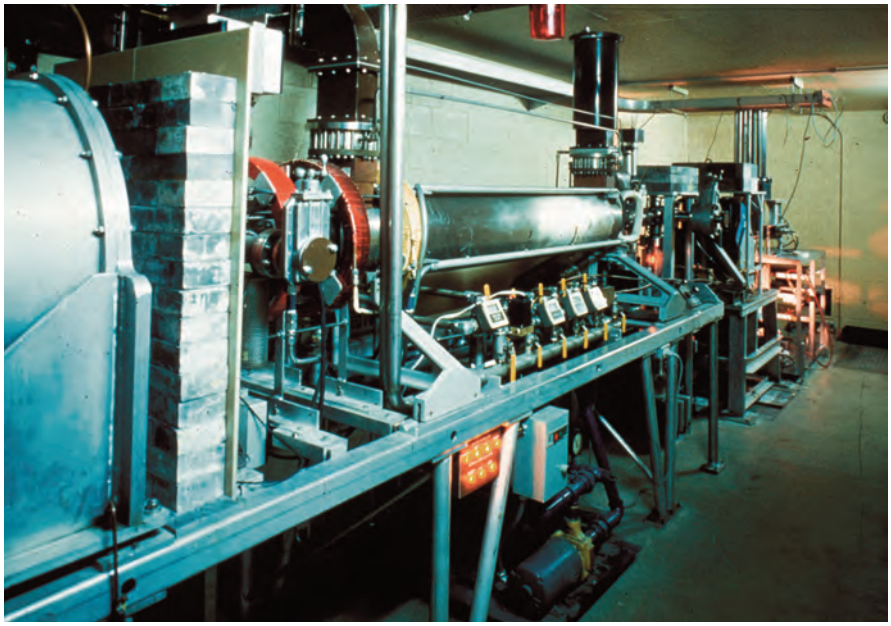
As light blue topaz can occur in nature, irradiation treatment of medium to light blue stones is hard to prove. However, deep, vivid blues are unknown in nature, so deeper colors provide strong evidence of treatment.

Depending on the source of the radiation, irradiated topaz might contain residual radioactivity that can be detected by a Geiger counter. The radioactivity is rarely high enough to be harmful, but it might be high enough to make the gems illegal to possess. The Nuclear Regulatory Commission (NRC) requires that irradiated gemstones entering or offered for sale in the US must have been tested for radiation levels by an approved laboratory. The NRC website has further information on guidelines for irradiated gemstones and how they affect the US gemstone trade.

KEY CONCEPTS

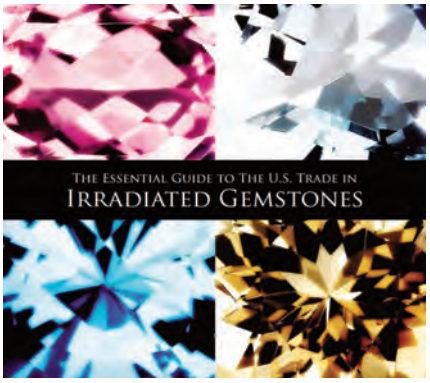
Irradiated color is not always stable, and exposure to heat or light can destroy it.

Commonly irradiated gems include topaz, tourmaline, and cultured pearl.

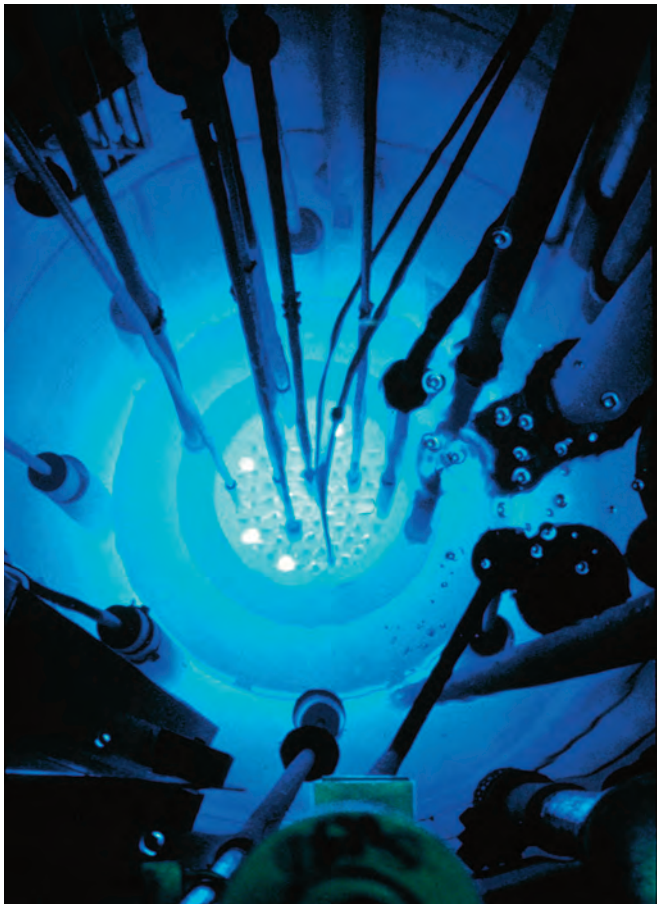


Courtesy IRT

This linear accelerator (linac) irradiates gemstones by firing a pulsed beam of electrons. Linacs are usually used on stones of about two carats or smaller because the electron beam won't completely penetrate larger stones. Millions of gemstones are treated this way.



The Essential Guide to The U.S. Trade in Irradiated Gemstones is published by the Nuclear Regulatory Commission: http://media.wix.com/ugd/38caab_fd1d86edf05e48ff96691e0631e8b3ad.pdf



Courtesy General Atomics

Gems can be irradiated in a nuclear reactor. The bluish glow is caused by gamma rays interacting with the electrons of the water molecules.

Robert Weldon/GIA

Irradiation gave the rough topaz a noticeable brown color. When irradiation was followed by heating, the topaz took on a stable blue.

ICA

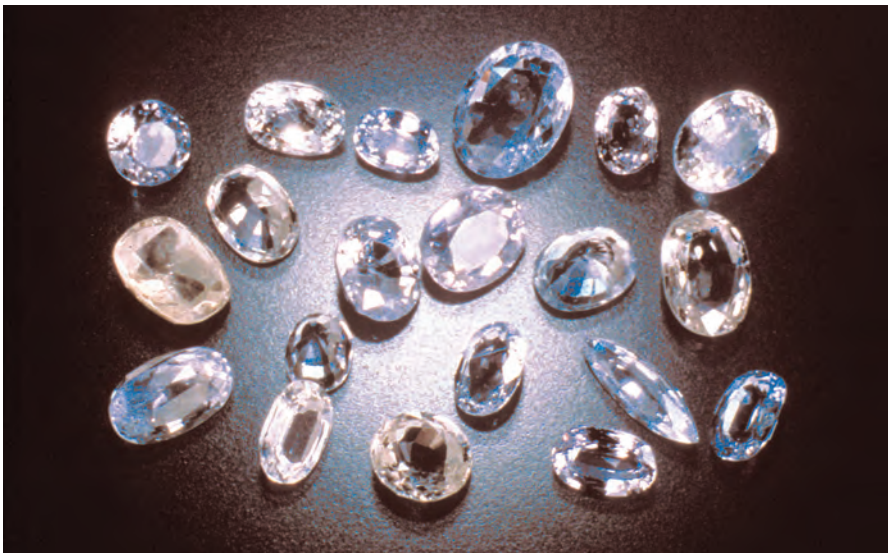
Irradiation can give beryl a golden color. The treatment is undetectable and stable under normal conditions.

Tino Hammid/GIA

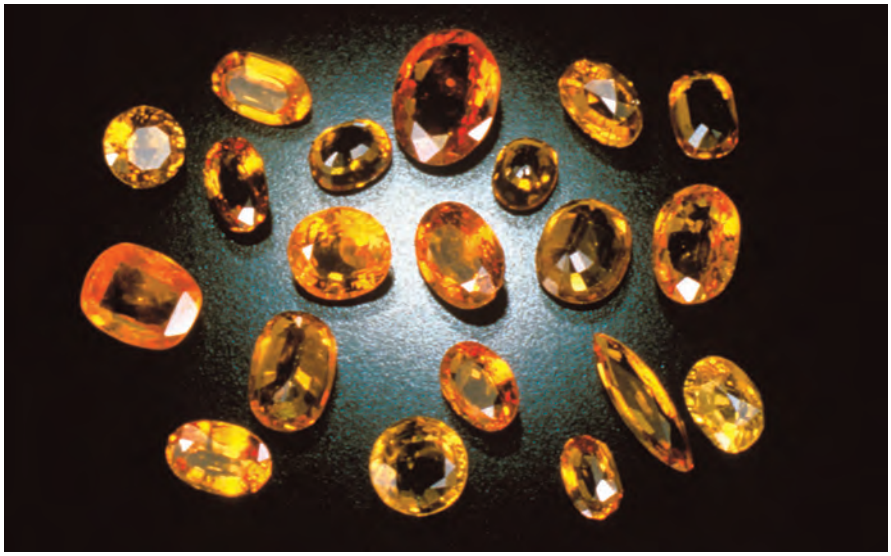
Irradiation can have a dramatic effect on gem color. The treatment can turn pale-colored tourmalines into darker rubellite varieties. Irradiation is not detectable in tourmaline.

Light-colored tourmaline can be irradiated to a dark pink or red color. So far, this treatment is not detectable, and its color seems to be as stable as the color of naturally colored tourmaline. The color of irradiated golden beryl is stable to about 250°C (482°F), and is also undetectable.

Some irradiated color fades fairly rapidly, which can help with detection if you can observe a gem that's exposed to heat or light over a period of time. This is the case with the treated colors of yellow-orange sapphire and green spodumene. Irradiation can cause natural beryl to match the intense blue color of untreated Maxixe (ma-SHE-she) beryl, a rare variety from Brazil. But the irradiated color fades quickly. Unfortunately, heat or light can also cause the natural color to fade in a short time.



John Koivula/GIA



Shane McClure/GIA

Pale-colored corundum (top) can be irradiated to a deep golden color (bottom), but the color is not stable. It fades when the gems are exposed to heat or light.

Irradiation can be used to color cultured pearls. With Chinese freshwater cultured pearls like these, the treatment darkens the nacre and causes an iridescent, metallic sheen.

Freshwater cultured pearls can be irradiated to produce a wide range of colors. The irradiation affects the nacre layers and often gives the cultured pearls an intense metallic sheen with strong iridescence. Irradiation doesn't affect the nacre in saltwater cultured pearls. Instead, it colors the nuclei, which are made from the shells of freshwater mussels.

Bleaching and Impregnation

Bleaching—A treatment that uses chemicals to lighten or remove color.

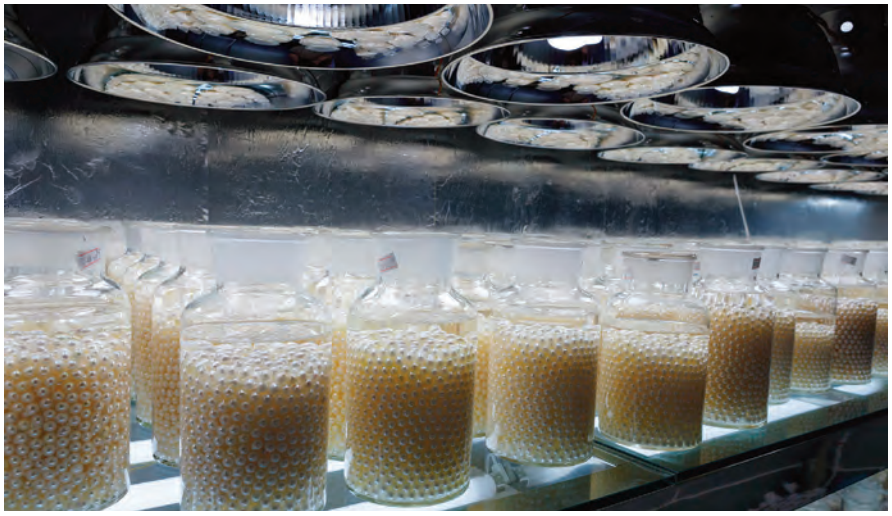
Impregnation—Filling of pores or other openings with melted wax, resin, polymer, or plastic to improve appearance and stability.

Bleaching is a treatment that uses chemicals to lighten or remove color. Many light-colored cultured pearls are bleached to remove dark spots and produce uniform color.

In *impregnation*, melted wax, resin, polymer, or plastic fills pores or other openings and then solidifies. It improves the appearance—including luster, translucence, and sometimes color—and also the stability of porous gems.

KEY CONCEPTS

Bleaching is a fairly common pearl treatment.

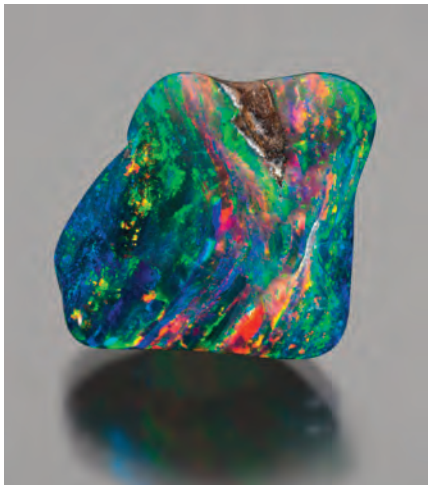


Valerie Power/GIA, courtesy Xuwen Pearl Paradise Co.

Almost all light-colored cultured pearls are bleached, often in diluted hydrogen peroxide, while being exposed to light. The treatment removes dark spots caused by organic matter and creates a more uniform color.

Tino Hammid/GIA

The brownish stains in the untreated jadeite on the left can be bleached out. This would leave voids in the surface that are then impregnated with a polymer. The result is a significant improvement in the jadeite's appearance, as seen in the piece on the right.



Robert Weldon/GIA

This Brazilian opal was dyed and impregnated with plastic. The treatment produced a dark bodycolor and enhanced its play-of-color.

Robert Weldon/GIA

The demand for turquoise is so strong that low-quality material is polymer impregnated and pressed into a composite material to make it marketable. The treatment is sometimes extensive enough to alter the material's gemological properties.

Colorless impregnation is used alone in some stones, including turquoise and opal. In other stones, it's used along with bleaching. Jadeite treated with this combination appeared in the 1990s. First, the stone is bleached with acid to remove any brown component in the jadeite's color and to clean out debris. Then it's impregnated with a polymer to fill any voids left by the acid treatment, as well as any surface-reaching cracks and pits. Bleaching jadeite with acid makes it brittle and causes some durability problems. The polymer restores some of that durability. You'll learn more about the classification of jadeite treatments in Assignment 18.

KEY CONCEPTS

Jadeite is often treated with a combination of bleaching and impregnation.

KEY CONCEPTS

Dyeing is one of the oldest gem treatments.

Dyeing—A treatment that adds color or affects color by deepening it, making it more even, or changing it.

Quench crackling—A rapid heating and cooling process that produces fractures in a stone so it will accept dye.

Dyeing

Dyeing—adding or modifying color—is one of the oldest gem treatments. It only works on gems with porous surfaces (like lapis lazuli, chalcedony, jadeite, coral, opal, and turquoise) or gems that have surface-reaching fractures that can accept the dye. Light-colored corundum with surface-reaching inclusions is often dyed to a deep red color. Also, a recent treatment of porous Ethiopian opal by dyeing can result in a rich purple color.

If the gem lacks surface-reaching features, treaters can use a technique called *quench crackling*. They rapidly heat and cool the gem, causing a pattern of small cracks that allow dye to penetrate the gem's surface. Quench-crackled rock crystal is sometimes dyed to imitate other gems. Colorless quartz and beryl can be quench-crackled and dyed green to imitate emerald.

Shane McClure/GIA

Aggregate quartz can be dyed green and used as a jadeite imitation.

Maha Tannous/GIA

The trade uses the name black onyx for a very popular dyed chalcedony used in jewelry. The black color is created by a sugar-acid chemical reaction.

Robert Weldon/GIA

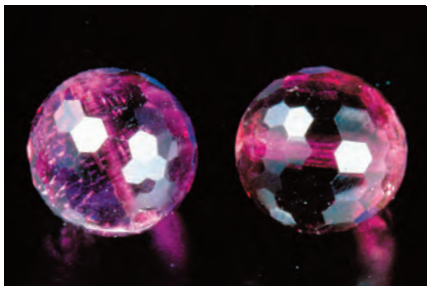
When this opal appeared on the market, its purple bodycolor raised concerns about its origin. It was reportedly from Mexico, but gemological analysis showed that it was actually porous opal from Ethiopia that owed its rich color to dyeing.

Maha Tannous/GIA

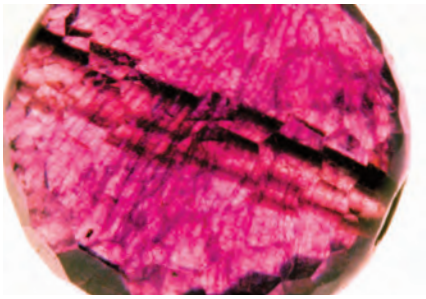
Non-porous materials with no surface-reaching fractures must be quench crackled before they'll accept dye. This quartz was quench crackled and dyed green to imitate emerald.

Nicholas DelRe/GIA

Quench-crackled quartz is often dyed red to imitate ruby.



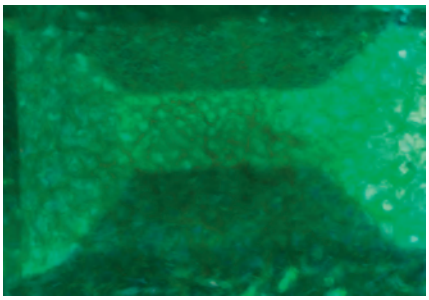
Nicholas DelRe/GIA



Nicholas DelRe/GIA

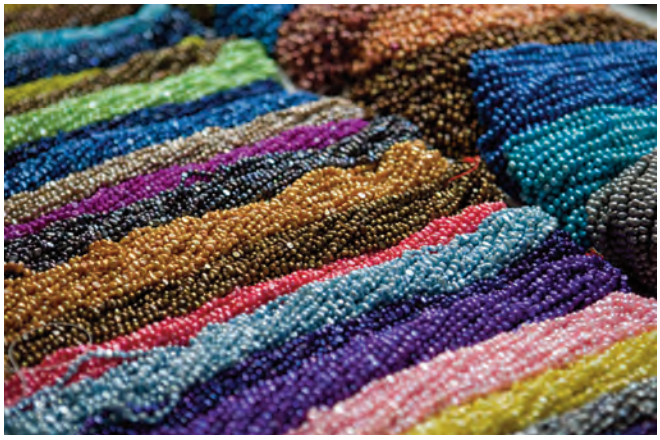
Transparent colorless quartz is often quench crackled and dyed various colors. When the resulting color is purple, it can imitate amethyst (left). Under magnification, the dye concentrations are evident in the surface-reaching fractures (right).

Terri Weimer/GIA



Terri Weimer/GIA

When quartz is quench-crackled and dyed green, it makes an effective emerald imitation (left), but closer examination reveals a characteristic honeycomb pattern of cracks with dark green dye concentrations (right).



Valerie Power/GIA

The porous nature of pearls makes them ideal candidates for dye treatments. These freshwater cultured pearls at a market in Zhuji, China, display a variety of unnatural dye-produced colors.

Acetone can remove the dye from lapis. Some types of dye might also simply come off with handling. Impregnation with plastic can increase the dyed color's durability.

KEY CONCEPTS

Commonly dyed gems include cultured pearl, lapis lazuli, chalcedony, and coral.

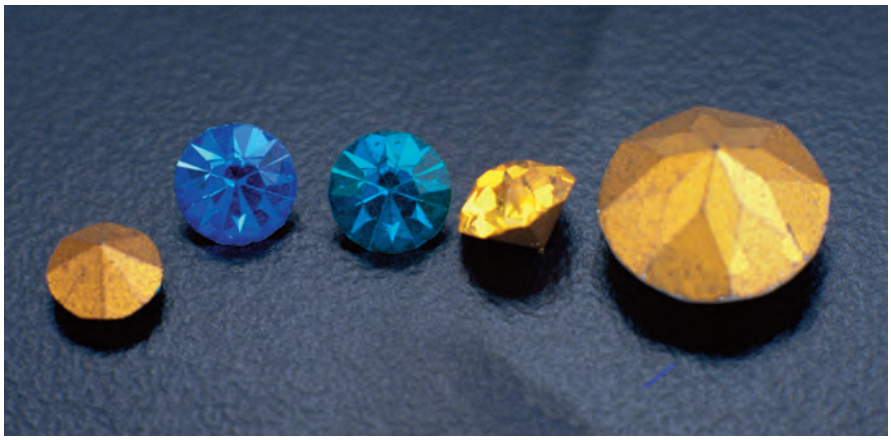
Cultured pearls are often dyed. Dyed pearls might show dye concentrations in drill-holes or in surface imperfections in the nacre. Some pearls and opals are treated with light-sensitive silver nitrate to darken them. While not a true dye, the treatment turns them almost completely black.

Lapis lazuli is commonly dyed to improve its appearance. The dye colors the gem's calcite component blue so the texture appears more even. To test for the presence of dye, wipe the back of the lapis with an acetone-dipped cotton swab. If the stone was dyed, some of the dye might come off. This isn't always a good test, however. Dyed lapis is sometimes impregnated with plastic to improve luster and seal in the dye.

Some jadeite is dyed, and some is bleached, then dyed, and finally impregnated with a polymer. The polymer seals in the dye and stabilizes the treated gem's surface. Treaters can also add dye to the impregnation materials in order to seal the surface of a porous material—frequently lower-quality turquoise. This enhances color and increases durability in a single step.

Lapis lazuli can contain a high percentage of calcite, which lowers its quality.

Dyeing the unattractive calcite areas blue results in uniform color.



Robert Weldon/GIA

Foil backing was once a very common gemstone treatment. It's less common today, but foil-backed gems like these glass imitations still appear in the market.

Surface Modification

Surface modification is an age-old gem treatment. It simply involves altering a stone's appearance by applying something to its surface. Usually, the aim is to deepen or induce color. The three basic types of surface modification are backing, coating, and painting.

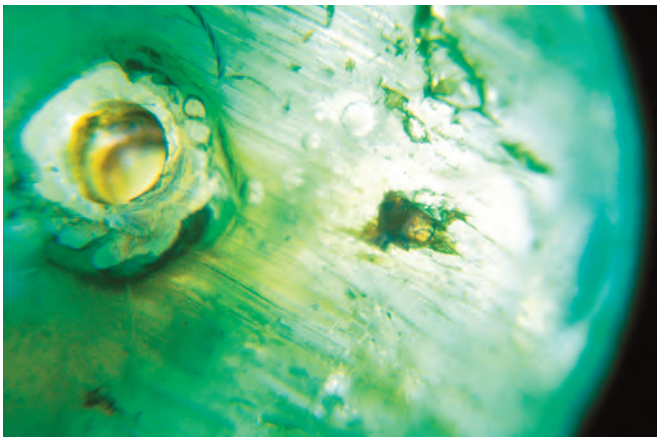
Surface modification—Altering a gem's appearance by applying backings, coatings, or coloring agents like paint.

In the past, many substances—such as colored foils, paints, and inks—were applied to the backs of gems to produce color that's visible through the crown. Also, patterned foil backings were used in some stones to give the appearance of stars.

Beryl, corundum, quartz, tanzanite, jadeite, and pearl might be treated with a variety of colored coatings, including plastic. Low-luster pearls can be coated to give them a shiny appearance. A coated pearl often has an unusually smooth surface when viewed under magnification. This gives away the fact that the pearl's shine is manmade.

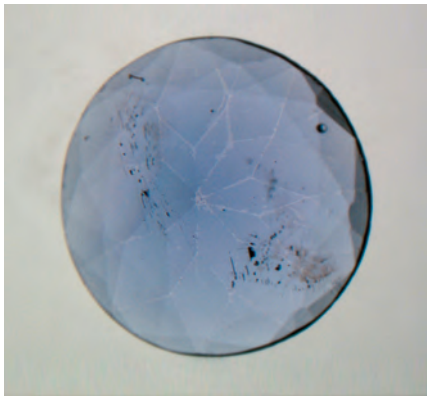
Nicholas DelRe/GIA

Beryl beads can be coated with green plastic to imitate emerald.



Nicholas DelRe/GIA

Magnification reveals gas bubbles trapped in the plastic coating.



Shane McClure/GIA

Blue coatings can make tanzanite's color seem better than it actually is. When immersed in water and examined in diffused lighting, this coated tanzanite shows where the coating was rubbed off along the facet junctions.

The stone on the left is an untreated emerald, while the stone on the right is a beryl coated with green plastic. The coating isn't durable, but without careful examination, the coated stone might fool a potential buyer.

Painting's purpose is always deception. Some dishonest people take advantage of the fact that just a small drop of green paint, ink, nail polish, or other colored substance on the girdle, pavilion, culet, or keel line of a near-colorless stone can make it look like an emerald.

As with other treatments, new surface modification techniques do occasionally appear. In recent years, treaters developed a way to deposit a thin layer of gold or titanium on fashioned topaz and quartz, as well as on quartz crystals. The metallic layer is so thin that it's transparent, but it's thick enough to affect selective absorption.

A gold layer gives the treated gem an iridescent blue or blue-green color. Many call the resulting gem "aqua aura," a combination of the Latin words for "water" and "gold."

Robert Weldon/GIA

Aqua aura is an iridescent blue-green color that comes from an extremely thin coating of gold. This treatment is commonly used on colorless or near-colorless quartz and topaz.

Maha Tannous/GIA

There's an iridescent coating on the pavilions of the faceted tourmalines and on the domed surface of the cabochon. The coating produces flashes of iridescent colors, which can be seen face up in the faceted stones and as concentric rainbow colors on the cabochon.

Thin-film coatings of diamond-like carbon (DLC) have been reported on CZ and some natural gemstones. Their purpose is to increase a gem's luster and durability. No third-party evidence or testing exists to verify their existence, and their presence can be difficult to detect.

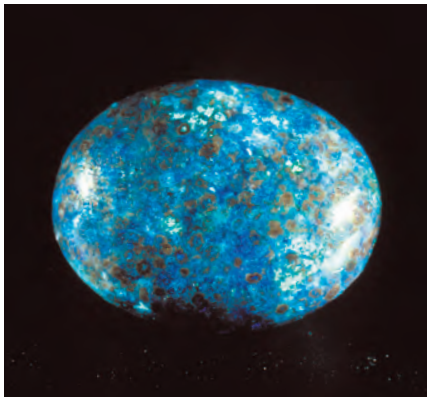
Sugar and Smoke Treatments

There are two different treatments that darken opals and bring out their play-of-color. They're called *sugar treatment* and *smoke treatment*. Both processes work only with opals that are porous. Before starting either treatment, the opals are formed into their finished shapes.

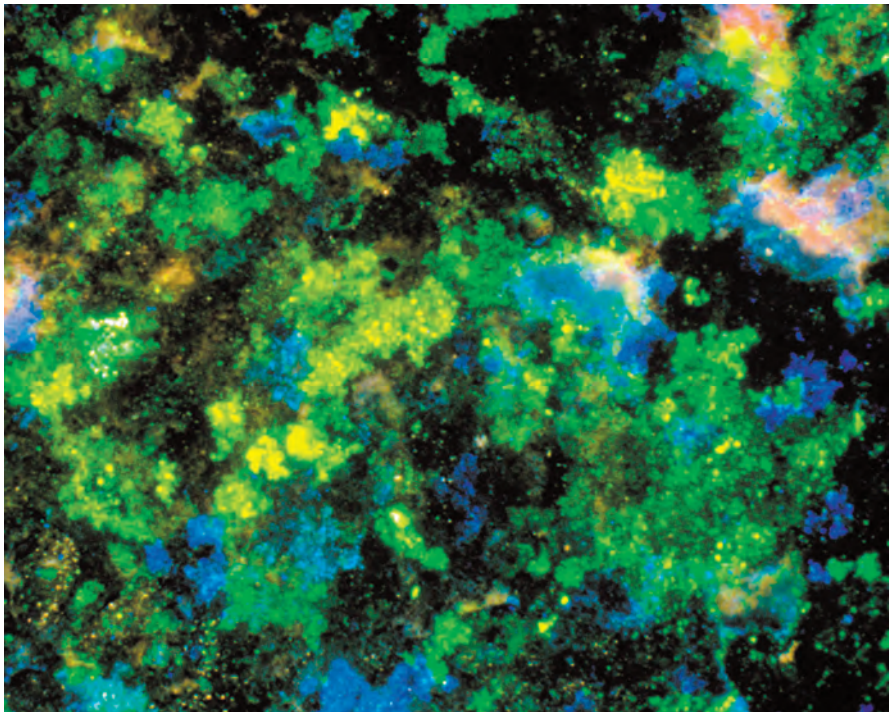
The first step in sugar treatment is to wash and dry the opals. The treaters then place them in a hot sugar solution and leave them for several days. After they're cooled and rinsed, they're placed into sulfuric acid that is heated to 100°C (212°F). They remain there for one to two days. The acid converts the sugar into carbon, which darkens the opal's color and dramatically enhances its play-of-color. Finally, the opal is thoroughly washed and prepared for polishing.

Sugar treatment—Soaking an opal in a hot sugar solution and then in sulfuric acid to darken it and bring out its play-of-color.

Smoke treatment—Heating a wrapped opal until smoke or ash penetrates its surface to darken it and bring out its play-of-color.



When porous opal is soaked in a hot sugar solution for several days and then in heated sulfuric acid for one to two days, the sugar converts to carbon. This darkens its bodycolor and brings out its play-of-color.



Robert Weldon

Sugar treatment penetrates only a shallow layer of a treated opal. Magnification reveals areas on the surface that resemble small dark spots.

Mike Havstad/GIA

As with sugar treatment, smoke treatment starts with porous opal with weak to no play-of-color. Treatment darkens its bodycolor and brings out its play-of-color. However, the effects are confined to a shallow layer.

Smoke treatment is not as common as sugar treatment. The opals are wrapped in layers of newspaper, then covered in aluminum foil or soaked in old crankcase oil and wrapped in brown paper. Heat is applied until the paper turns to carbon, which penetrates the opal. Another smoking method involves burying the stones in manure in an earthenware jar, then baking them over charcoal.

With experience, sugar and smoke treatments are relatively easy to identify. Sugar-treated opal has small dark areas that resemble pepper. Smoke-treated stones have a dark, patchy-looking appearance. Sugar and smoke treatments affect only a shallow layer below the surface, so the new color can be worn away.

Conditions in today's jewelry market make it absolutely essential for you to be aware of the wide variety of gem treatments. Sometimes a gem—such as a ruby with blue color zones—might be subjected to multiple treatments to make it marketable. Besides understanding how and why gems are treated, you should also understand how gemologists detect common treatments. It's also essential for you to understand the importance of full disclosure. At every level of the wholesale and retail jewelry industry, your success depends on it.

This assignment introduced you to some common gem treatments. Later in the course, individual gem assignments will provide more details on treatments that are unique to certain gems.

KEY CONCEPTS

Treatments that improve gem appearance and quality increase the supply of commercially important gems.

To help build trust in the gem and jewelry industry, all treatments—even suspected or probable treatments—should be disclosed as part of every transaction.

Gems that are commonly heat-treated include corundum, tanzanite, zircon, topaz, aquamarine, and amber.

When certain trace elements within a gem lose or gain electrons during heat treatment, it can change the way the gem absorbs light, altering its color.

Heat treatment can alter corundum color and create or eliminate phenomena and inclusions.

Low-temperature heating can improve the appearance of ruby and pink sapphire by removing blue color zones.

Low-temperature heating of corundum is much more challenging to detect than higher-temperature heating.

Producing blue color in geuda sapphire requires high-temperature heating in a reducing environment, followed by relatively rapid cooling.

Quantities of lattice-diffusion treated corundum, feldspar, and spinel had entered the gem market by 2015.

Lattice diffusion with heavier elements like titanium and chromium produces a shallow layer of color that might be removed by minor repolishing.

A combination of beryllium diffusion and heat treatment can improve color in some dark blue sapphires and make them more marketable.

The color resulting from lattice diffusion with beryllium can penetrate the entire stone.

Fracture filling is the most common form of clarity enhancement.

Today, almost all emeralds on the market are subjected to clarity enhancement.

Filling with glass or resin can stabilize highly fractured, otherwise unusable rough so it can be processed for jewelry use.

The proportion of filler in some lead-glass treated gems is so high that gem labs consider them composites or manufactured products.

Irradiated color is not always stable, and exposure to heat or light can destroy it.

Commonly irradiated gems include topaz, tourmaline, and cultured pearl.

Bleaching is a fairly common pearl treatment.

Jadeite is often treated with a combination of bleaching and impregnation.

Dyeing is one of the oldest gem treatments.

Commonly dyed gems include cultured pearl, lapis lazuli, chalcedony, and coral.

Key Terms

Bleaching—A treatment that uses chemicals to lighten or remove color.

Clarity enhancement—Treatment that improves the apparent clarity of a gem with a colorless or near-colorless filler.

Dyeing—A treatment that adds color or affects color by deepening it, making it more even, or changing it.

Flux—A compound that can dissolve another compound at a lower temperature than its own melting point.

Flux healing—Heat treatment in the presence of a flux that results in the sealing of a fracture or cavity.

Fracture (fissure) filling—Use of a colorless to near-colorless filler to conceal fractures and improve the apparent clarity of a gem.

Geuda—Milky, grayish, or brownish corundum that can be treated to a fine blue color.

Hardener—A chemical that treaters mix with some resins to cause them to solidify.

Heat treatment—A treatment in which a gem is exposed to rising temperatures to change its appearance.

Impregnation—Filling of pores or other openings with melted wax, resin, polymer, or plastic to improve appearance and stability.

Lattice diffusion—A treatment in which a gem is exposed to high temperatures and chemicals to allow penetration of color-causing elements.

Oxidizing environment—An oxygen-rich environment that surrounds a gem during heat treatment, causing certain color-causing trace elements to lose electrons.

Polymer—A liquid filling material that's very durable when it dries.

Quench crackling—A rapid heating and cooling process that produces fractures in a stone so it will accept dye.

Reducing environment—An oxygen-poor environment that surrounds a gem during heat treatment, causing certain color-causing trace elements to gain electrons.

Resin—A clear, viscous substance that's used to fill fractures in gemstones.

Smoke treatment—Heating a wrapped opal until smoke or ash penetrates its surface to darken it and bring out its play-of-color.

Sugar treatment—Soaking an opal in a hot sugar solution and then in sulfuric acid to darken it and bring out its play-of-color.

Surface modification—Altering a gem's appearance by applying backings, coatings, or coloring agents like paint.

Treatment—Any human-controlled process, beyond cutting and polishing, that improves a gem's appearance and/or durability and therefore its value.

Questions for Review

- Why are some gems treated?
- How does treatment affect value?
- Why is treatment disclosure important?
- What are the most common treatments?
- What stones are commonly treated?
- How durable are some gem treatments?

For Further Reading

GIA's course content comes from field research at gem mining, processing, and marketing centers, carried out by GIA subject matter experts and research scientists, as well as from publications on the GIA website and in GIA's peer-reviewed professional journal, *Gems & Gemology,* authored by GIA experts and worldwide contributors.

These references include source material for many of the course assignments and suggestions for your own research. You will not be tested on the information in any of the references provided below.

Scan the QR code above or go to https://www.gia.edu/library to access articles for further reading.

Assignment 1: Introduction

Gems & Gemology current issue:
https://www.gia.edu/gems-gemology

News and Articles:
https://www.gia.edu/gia-news-research

GIA Gem Project:
https://www.gia.edu/gia-gem-database

GIA Library recommended reading & bibliographies for gems and historical localities:
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Assignment 2: Gemstone Formation and Mining

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On the Trail of Africa's Hidden Gems with GIA's Field Gemologists (2015) GIA Research & News
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Assignment 5: Synthetics and Imitations

Synthetic Corundum

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