GEMOLOGY



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Book: Gemology

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1: INTRODUCTION TO GEMOLOGY

1.1: General Information on Gemology
1.2: Becoming a Gemologist

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1.1: General Information on Gemology

Gemology, the study and science of gems, can be as much an anthropological study as it is a mineralogical one. Gemstones, because of their remarkable beauty, durability, and rarity, have been granted a significance that helps us understand the history of mankind. The human race, from its infancy to present day, has sought to protect itself behind walls of mysticism and superstition reinforced with gem talismans that could be easily carried and hidden.

Ancient lore and legends associated with gems have, for the most part, been replaced with "rational" references of romance and poetic beauty, but precious stones remain the greatest universal talismans of wealth and power!

What is Gemology?

Gemology is the scientific study of gemstones, which often involves the study of mineralogical fundamentals such as formations, genesis, localities, physical properties and identification of gemstones. It includes the basic knowledge of structural, crystallographic, chemical and physical characteristics and properties of gems. It also involves the way in which gemstones are fashioned.

Special Gemology deals with categories and varieties of gemstones, synthetic stones, and imitations. Conventionally, the organic substances such as amber, pearls, coral and the non-minerals are also included in this subject of special gemology.

Practical Gemology refers to the application of the knowledge of characteristics and properties of gemstones in identification or separation of synthetics and imitations. Diamond grading is included in practical gemology.

What is a Gemologist?

A gemologist is someone who studies gemstones. Being recognized as a gemologist usually involves having credentials from one of the Institutes for Gem(m)ological Studies discussed below (see **Becoming a Gemologist**).

What are gemstones?

Gemstones are usually minerals but sometimes organic substances. What separates them from minerals, in general, is that they are used in jewelry or for ornamentation. That is a very thin line of separation, but usually we take 4 factors into account:

- Durability
- Rarity
- Beauty
- Acceptability

And, of course, there is a 5th factor:

- Fashion

All the factors above are relative in nature. For instance, amber has very poor durability, isn't very rare and in general is not highly priced. Yet it is considered to be a gem due to its beauty.

On the other hand, most sapphire has good durability but can be very unattractive and inexpensive. Only a small portion of all sapphires mined have good color/beauty. The same can be said for diamond; the vast majority of diamonds mined are used for industrial purposes because they lack the necessary beauty to be worn as jewelry.

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1.2: Becoming a Gemologist

Becoming a gemologist in general means hard work and commitment. A wise teacher once said, "You are only permitted to read books related to our trade and a religious book of your choice from now on . . . for the rest of your life".

Education

Although you can find very useful information on the Internet (like here), we **strongly** suggest that you take formal training from one of the established institutes listed below. Our editors have graduated from at least one of them.

Some of the online gemological schools are basically run by one person and in case of mishap the school will cease to exist, aswell will be your "diploma".

Gem-A

Better known as The Gemmological Association of Great Britain, this school is London based with departments worldwide. It offers distance tutoring as well as teaching centers.
The primary focus is on in-depth theory and the exams are the hardest to take in the industry. A fellowship of Gem-A means esteem.

Costs for Gem-A's distance learning courses:

Foundation correspondence course GBP 1500.00
Diploma correspondence course GBP 1695.00 (on completion is granted the FGA title).

Gem Diamond diploma course GBP 1795.00 (on completion is granted the DGA title).

Website http://www.gem-a.info/

GIA

The Gemological Institute of America is the most prestigious and respected institute for gemology within the United States. Its main location is in Carlsbad, California, with facilities in New York and Los Angeles. Courses may be completed by distance learning via the online "virtual campus". It was established in 1931 by Robert Shipley, and currently the GIA is the world's largest and one of the most respected nonprofit institutes of gemological research and learning internationally. It employs nearly 900, including scientists, diamond graders, and educators.

Costs:

On campus (CB/NY/LA): 6 month continuous program (780 hours) $14,695

Distance Education: GEM130, GEM230, GEM230L, GEM120, GEM220,GEM220L, GEM240, GEM240L (Maximum completion time: 63 months) $6,975 ($7,420 International)

What you earn: Graduate Gemologist Diploma, Graduate Diamonds Diploma, Graduate Colored Stones Diploma
Website: www.gia.edu

AIGS

Thailand is in the heart of Southeast Asia's gem and jewelry production and trading area. It presents you with an extraordinary opportunity to learn gemology in theory and practice while experiencing the gem business in a three dimensional way.

The A.G. program, which leads to the A.G. (Accredited Gemologist) Diploma, includes the four core courses:

E102: Gem Identification

E103: Diamond Grading and Pricing

E201: Colored Stone Grading and Pricing

E301: Synthetic and Treated Gem Identification.

These 4 courses can be studied in any order, in one or several study periods at AIGS. It is recommended that “Gem Identification” be studied before “Synthetics and Treated Gems”.

Students enrolling in the entire A.G. program are entitled to a 15% discount off the total tuition fee. Courses must be taken within one year of the first date of payment. Beyond the one year period, students will be subjected to any tuition increases that may have occurred. (Example: Old fee = 20,000 Baht, New fee in effect since date of enrollment = 22,000 Baht, Additional amount to be paid = 2,000 Baht.)

Living expenses and general overhead are amazingly low compared to countries such as USA, Japan and most of Europe. Students studying at the AIGS can live with a US$600 to US$1000 budget per month including housing near the school, weekend field trips, restaurants and entertainment. Of course, you can spend much more if you want to, but this amount yields a comfortable lifestyle!
Website: http://www.aigsthailand.com/

DGemG

The Deutsche Gemmologische Gesellschaft (The Educational Training Center of the German Gemmological Association) is located in Idar-Oberstein, Germany. Idar-Oberstein is an international colored stone gem capital, where gem cutting has been traditionally mastered for centuries. It is currently bustling with local gem artists and studios. It has, perhaps, the highest per capita population of gem cutters in the world! The German Gemmological Association was founded in 1932. Its laboratories have modern state of the art equipment, and one of the most extensive colored and exotic gemstone collections available.

Costs:

Euro 5,800.00

Website:http://www.dgemg.de/gemmologen_eng/index.php?seite=home

FGAA

The Gemmological Association of Australia (GAA), founded in 1945, is Australia’s historic trade-accepted non-profit educational authority for gemology.
They offer gemological courses in 6 state divisions.

Costs: contact one of the six state divisions for pricing.

Website: www.gem.org.au

CGA

The Canadian Gemmological Association, based in Toronto Canada, is a Canada-wide professional organization which has set the standard for excellence in the practice of gemology. It was founded in 1958 by Dean S.M. Field, and has since provided training in gemology to persons dealing with gemstones in the jewelry industry and to hobbyists for better appreciation and possible new career opportunities within gemology.

They offer a one-year correspondence course as well classes on location.

Costs:

The two-year correspondence course, leading to a Diploma in Gemmology and a Fellowship (FCGmA) in the Canadian

Gemmological Association, is offered from CAD 2,150.00

Website canadiangemmological.com

Post Graduate

After gaining your gemological diploma, the real fun starts. You will know the basics and more importantly, you will know how to understand the many articles published in various periodicals.
If you keep up as a consumer of the gemological literature and are involved with continuing education, you will be a good gemologist one day.

Career Opportunities

As with any profession, it is all up to you what you will become and what your salary will be.

Think of a gemological diploma as if you have finished your first year in college and the pay rate according to that when you start out. You will be qualified to find jobs in gemological laboratories worldwide and will be the key figure in the local jewelry store. You may become manager of a company, start your own gem-trading business, become an appraiser, or you might just stay shoveling municipal gardens etc. Anything you set your mind to. Pay rate is according to experience and market.
Our best advice is to start networking from the start and to seek a new employer every few years so you can gain as much know-how as you can.

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2: ORIGINS OF MINERALS

2.1: Igneous (Magmatic) rocks
2.2: Sedimentary rocks
2.3: Metamorphic rocks
2.4: External Links
2.5: Luster

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2.1: Igneous (Magmatic) rocks

Basic

By the cooling down of magma, atoms are linked into crystalline patterns and subsequently different minerals are formed. When the formation takes place in the depths of the earth's crust (approx. 33km deep) quite large rocks may be formed (for instance, granites).

Igneous rocks are formed and created by magmatic processes in the earth. To form very large crystals of rare minerals, exceptional conditions are needed. For instance, a rock called pegmatite is formed by the crystallization of magma enriched with water in the veins of other rocks, and may contain beryl, tourmaline and topaz.

Igneous rocks are divided into two types -- volcanic rock (extrusive) and plutonic rock (intrusive) -- depending on where the magma cools.

Volcanic or extrusive rock

This is rock that is formed on the surface of the earth. In contact with air or seawater, molten rock cools rapidly and either quenches to a glass (like obsidian) or forms small crystals (basalt). Volcanic rocks are usually finely grained or glassy in structure.

Basalt is an extrusive rock, finely grained due to its rapid cooling. It largely consists of tiny feldspar and pyroxene crystals (like diopside and enstatite). Some basalts contain gemstones like corundum, zircon and garnets.

Another volcanic rock is called kimberlite. Kimberlite pipes are the most major source of diamond.

Occasionally, varieties of volcanic glass, obsidian, are cut and fashioned as gemstones. Obsidian is an amorphous mineraloid with the hardness of approximately 5.5. Varieties of obsidian include:

- Snowflake obsidian (with inclusions of the mineral cristobalite)
- Rainbow obsidian
- Red mahogany obsidian
- Silver sheen obsidian
- Midnight lace obsidian
- Pumpkin obsidian
- "Apache tears" obsidian

Plutonic or intrusive rock

When molten rock solidifies within preexisting rock, it cools slowly, forming plutonic rocks with larger crystals. They tend to be coarse grained.

Granite is a coarse grained intrusive rock which contains the minerals quartz and feldspar, and usually carries mica or hornblende. In some circumstances, granite undergoes "fractional crystallization", a process where slow cooling creates crystals of different minerals as they form at different temperatures.

Minerals of the pegmatite group are among the last to be formed, often occurring as veins penetrating their surroundings.

Associated minerals that find their origin in igneous rocks:

- Beryl
- Chrysoberyl
- Corundum
- Diamond
- Garnet

- Feldspar
- Peridot
- Quartz
- Spinel
- Topaz
- Tourmaline
- Zircon

Advanced

Stages of the igneous or magmatic cycle

The stages of the igneous or magmatic cycle are as follows:

1. Early magmatic phase (early crystallization) from the fiery hot magma:

- Chromite
- Magnetite
- Titanium magnetite

2. Liquid magmatic phase (main crystallization) 1500-600 degrees C:

- Spinel
- Zircon
- Apatite
- Peridot
- Diamond

3. Pegmatite phase (rest crystallization) 700-400 degrees C:
The residual part of the magma, which is rich in fluxes, is known as the pegmatite stage. The melt becomes a watery solution as solidification proceeds. Because of this fluidity, the liquids can penetrate fissures and cracks in the surrounding rocks. Under the concentrated pressure and temperatures, individual crystals form that can measure several centimeters, and occasionally several meters! The prismatic crystals grow perpendicular to the walls of the vein. Pegmatite veins are some of the best examples of gemstone formation.

- Tourmaline
- Beryl
- Quartz
- Feldspar
- Zircon
- Apatite
- Brazilianite
- Graphite
- Muscovite
- Lepidolite

4. Pneumatolytic phase 500-300 degrees C:
Minerals formed in this phase form at lower temperatures and rising pressure. Superheated volatile components are involved. The most prominent of these components is water vapor, boron and fluorine gases. Under the influence of these vapors, other minerals are often formed in the contact zone of limestone.

- Topaz
- Euclase
- Vesuvianite
- Fluorite
- Cassiterite
- Sheelite

- Wolframite

5. Hydrothermal phase 400-50 degrees C:
This is a process associated with igneous activity that involves heated or super-heated water. Water at very high temperature and pressure is an exceedingly active substance, capable of breaking down silicates and dissolving many substances normally thought to be insoluble. This is the last stage of minerals that can be considered to be formed directly from magma.

- Gold
- Silver
- Emerald (Colombian)
- Beryl
- Quartz
- Barite
- Pyrite
- Dolomite
- Calcite

Expert

Zircon to calculate the age of the earth

Zircon forms in granites deep in the earth's crust (plutonic rock). Through movement of tectonic plates, this granite is brought to the surface and starts mountain building. Through erosion, the granite (and the contained zircon) builds sediments which will eventually be buried deep enough to transform into metamorphic rocks.

Zircon has two important properties:

1. Relative high hardness
2. Resistance to chemical attacks

Due to its hardness of 7.5 on the scale of Mohs, the zircons usually survive the sedimentary process intact. Because of its resistance to chemical attacks, zircon will survive the contact metamorphism process which is trying to attack it with heat and pressure. The latter is important as the liquid mass surrounding the zircon will cause a new rim to be formed around the old zircon, just like the formation of tree rings. This first cycle usually will take hundreds of million years.

The old crystal with its newly formed rim is then pushed up again through tectonic plate interactions, then this geologic cycle repeats itself.

A third and well known property of zircon is that it can accommodate radioactive elements like uranium. Uranium has the ability to decay into lead at a fixed time rate. Calculation of the uranium-lead ratio may give a clue of the age of the zircon (and thus Earth's age). However, lead may leak from the zircon, disturbing the uranium-lead ratio.

Fortunately, scientists found a new way of calculation by using isotopes. The uranium-238 isotope (with a half-life of 4.468 billion years) decays to lead-206, while uranium-235 (with a half-life of 703.8 million years) decays to lead-207. The "secondary ion mass spectrometry" (or SIMS) technique is used for this kind of measurement. By measuring both 'parent-daughter' decays of both these processes, an accurate age of the zircon can be calculated -- that is, if both measurements are consistent (which is not always the case).

The Isua rocks on Greenland are a source for this way of dating the earth's age. Current calculations indicate Earth is 4.6 billion years old.

Further reading: A birthstone for earth

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2.2: Sedimentary rocks

Basic

The sedimentary cycle is the second largest cycle in mineral and rock formation. Sedimentary rocks are formed by erosion, transport in rivers, ice etc. and involve the decay and disintegration of a preexisting rock mass. Usually, there are no new minerals formed, only found.

When these particles eventually settle, they form alluvial gravels, sands or clays. When they are either cemented or compressed, then they form sedimentary rocks such as conglomerations, sandstones, and limestones.

Chemical action in the environment leads to some material dissolving in water. Eventually, the water may evaporate and deposits of borax and other salt "evaporates" may form this way.

Plant and animal remains are commonly incorporated among the rock fragments and these may be preserved as fossils.

Many gemstones are found in "alluvial deposits". These deposits have their origin in the destruction of the original rocks and the resulting materials by rivers, floods, and glacial movement. During this movement, the heavier minerals tend to remain relatively close to the source, whilst lighter minerals are carried further away.

The heavier and harder materials do not wear as much as the lighter ones and tend to retain more of their crystal shape. Stones such as sapphire and topaz do not show as much abrasion as softer minerals like quartz.

However, due to the continuous grinding and tumbling over a period of time, a large number of gem minerals are found as rounded "water-worn" pebbles. The gem gravels in Sri Lanka contain a wide variety of such minerals.

Because of their supreme hardness and density, many diamonds survive the sedimentary processes and are frequently found in alluvial deposits.

Minerals found in sedimentary rocks:

- Beryl
- Opal
- Quartz
- Turquoise
- Malachite
- Azurite
- Chrysoprase
- Chrysocolla

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2.3: Metamorphic rocks

Basic

The metamorphic cycle is the third largest cycle in mineral and rock formation. Metamorphism is the alteration of mineral paragenesis (the order of formation) after their deposition, by external action such as contact with magmetic rocks, regional changes in the pressure and temperature (e.g. contact metamorphosed limestones, crystalline schists, etc.). The consolidated rocks are altered in composition, texture or internal structure through pressure, heat and new chemical substances.

There are two kinds of metamorphism: **Regional** and **Contact**.

1. *Regional metamorphism* is caused due to a rise in temperature and directed pressure, affecting the earth's crust.
2. *Contact metamorphism* is caused when magma is intruded into a preexisting rock mass. The heat and pressure of this magma cause a metamorphic change in the rock it intrudes.

Both igneous and sedimentary rocks can change in texture or chemical composition as the result of either contact or regional metamorphism. Thus existing rocks change into new types of rocks. They are usually harder and denser than the original material.

For example, shale may alter into slate and further metamorphose into schist. Limestone is converted into marble. Sometimes schists contain gem minerals like garnet, emerald, and corundum.

Some minerals that grow in metamorphic rocks are:

- Beryl
- Corundum
- Danburite
- Garnets
- Iolite
- Lapis lazuli
- Jadeite
- Nephrite
- Spinel
- Alexandrite
- Andalusite

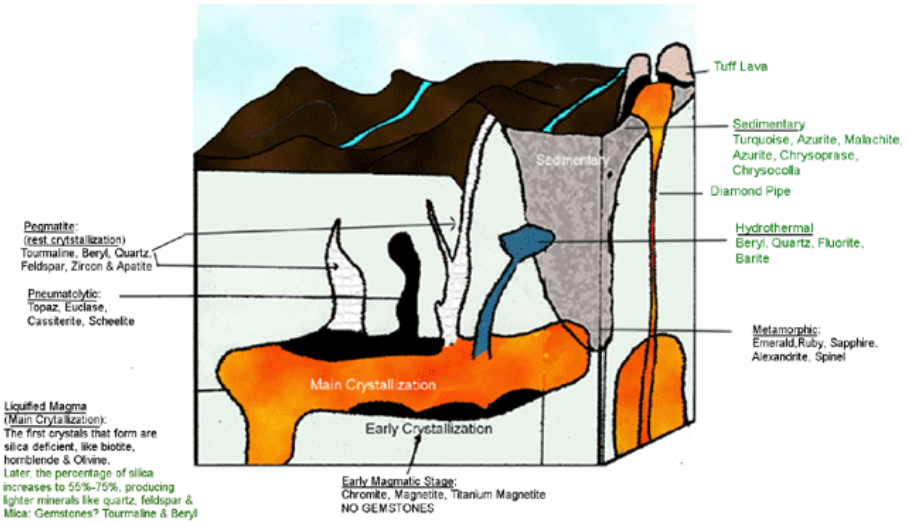


Figure 2.3.1

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2.4: External Links

FUNDAMENTALS OF PHYSICAL GEOGRAPHY

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2.5: Luster

The Bottom Line on Luster - Here on Top!

In an introductory course, luster is a described as a property of light reflection that separates metallic from non-metallic minerals.

Determining luster can be difficult for a beginner. A dark colored sample of weathered magnetite (metallic luster) might be mistaken for an earthy sample of hematite (non-metallic luster), but these two will differ in other properties, for example magnetism. Other physical properties are more easily and definitively determined, such as electrical conductance, hardness, streak, reaction to acid, magnetism, etc. leading to fewer errors and a faster route to the identification of a mineral. Check the Mineral Bank for this and additional information.

Bottom Line: **I created a replacement activity for this traditional observation of luster - the flashlight circuit test. My students find it fast and fun. Results are almost always unequivocal. And all that's needed are $1 flashlights. Check out the section on electrical conductance for details.**

Errors/Suggestions: Contact Scott Brande (see footer) or post on Discussion Forum.

The Bottom Line on Luster - Here on Top!

What is Luster?

Learn Luster in Single Crystals

Learn Luster in Rocks

Demonstration of Luster

Instructions: The Luster Test

Ready For A Practice Quiz?

What is Luster?

Background. Luster is a property of the mineral response to light. When light illuminates any matter, you may see see one of several different responses.

- light may reflect off the surface, like from a mirror
- light may reflect off the surface and be partially absorbed (penetrate) into (and perhaps through) the mineral

Although the appearance of a mineral may vary with conditions of illumination, we will simplify our interpretation into two broad categories - **metallic** and **non-metallic** luster.

- **Metallic luster** means reflected light resembles a **polished metal surface**.
- Otherwise, the appearance of reflected light is termed **non-metallic** and this appearance may vary. Terms used for non-metallic luster include **glassy** (or "vitreous"), pearly (like mother-of-pearl), etc. For more details about the different terms given for luster, consult this link - luster in mineral identification.

Learn Luster in Single Crystals

Metallic luster. Cubic single crystal of galena. The crystal is **opaque**.

Image by **R.Weller/Cochise College**

Non-metallic luster. Cubic single crystal of halite. The crystal is **transparent**.

Image by **R.Weller/Cochise College.**

Metallic luster. Octohedral crystals of magnetite. The mineral is **opaque**.

Image by **R.Weller/Cochise College**

Non-metallic luster. Octohedral crystals of fluorite. These crystals are **transparent**.

Image by **R.Weller/Cochise College.**

Metallic luster - brownish cubic crystals of galena.

Image by **R.Weller/Cochise College**

Non-metallic luster - purple cubic crystals of fluorite.

Image by **R.Weller/Cochise College**

Non-metallic luster - single crystal of quartz (smoky). Note that you can see the inside of the crystal. The crystal is **transparent**.

Image by **R.Weller/Cochise College**

Non-metallic luster - single crystal of calcite (dogtooth spar). Note that you can see that light penetrates inside of the crystal. The crystal is **translucent**.

Image by **R.Weller/Cochise College**

Learn Luster in Rocks

A mineral, by definition, is a solid chemical compound with ions and molecules arranged in long-distance, repetitive, geometric order. The above examples show single crystals of significant size for handling and observation.

The determination of luster becomes more difficult and uncertain as crystal size becomes smaller, eventually microscopic. That's why you'll need to examine a sample to determine multiple properties that help you to narrow down a list of possible names for identification. Don't spend too much time on evaluating luster of rock samples. Make sure you observe other properties (e.g., hardness, streak, cleavage, etc.)

Here are some examples of luster in rocks (multi-crystalline aggregates) where crystals approach microscopic in size, making luster more difficult to evaluate.

Metallic luster - single crystal of graphite.

Image by **R.Weller/Cochise College**

Metallic luster - crystalline aggregate of graphite.

Image by **R.Weller/Cochise College**

Metallic luster - fine-grained crystals of pyrite (brassy yellow).

Image by **R.Weller/Cochise College**

Non-metallic luster - coarser-grained crystals of quartz (gray).

Image by **R.Weller/Cochise College**

Metallic luster. Rock composed of fine-grained graphite.

Image by DerHexer, Wikimedia Commons, CC-by-sa 4.0 (https://commons.wikimedia.org/wiki/File:Harvard_Museum_of_Natural_History._Graphite._Colombo_Mines,_(Ceylon)_Sri_Lanka_(DerHexer)_2012-07-20.jpg), https://creativecommons.org/licenses.../4.0/legalcode

Non-metallic luster. Rock composed of fibrous actinolite. Pen for scale. Mineral collection of Brigham Young University Department of Geology, Provo, Utah. Photograph by Andrew Silver. No BYU index. This image is in the public domain pursuant to an agreement dated August 10, 2006 between Peter J. Modreski, USGS Communications and Outreach, and the Brigham Young University (BYU) Geology Department

Metallic luster - specular hematite. Note the mirror-like reflection.

Image by James St. John (https://commons.wikimedia.org/wiki/File:Specularite_(high-grade_iron_ore)_(Soudan_Iron-Formation,_Neoarchean,_~2.69_Ga;_Soudan_Mine,_Soudan,_Minnesota,_USA)_2_(18844370038).jpg), „Specularite (high-grade iron ore) (Soudan Iron-Formation, Neoarchean, ~2.69 Ga; Soudan Mine, Soudan, Minnesota, USA) 2 (18844370038)“, https://creativecommons.org/licenses/by/2.0/legalcode

Metallic luster - galena. Note mirror-like reflection.

Image by Modris Baum (https://commons.wikimedia.org/wiki/File:Argentiferous_Galena-458851.jpg), „Argentiferous Galena-458851“, marked as public domain, more details on Wikimedia Commons: https://commons.wikimedia.org/wiki/Template:PD-author

Metallic luster - magnetite. Note mirror-like reflection.

Image by Rob Lavinsky, iRocks.com – CC-BY-SA-3.0 (https://commons.wikimedia.org/wiki/File:Magnetite-4jg32a.jpg), „Magnetite-4jg32a“, https://creativecommons.org/licenses.../3.0/legalcode

Demonstration of Luster

Watch the video demonstrations below.

Instructions: The Luster Test

Caution - learning to identify the particular type of luster takes practice, and for the beginner, may be difficult. Other properties are more easily determined with less potential error, and lead more directly to the identification of the mineral. So we downgrade the importance of luster as a diagnostic property. For example, if one misidentifies a mineral as having a non-metallic luster when it actually exhibits a metallic luster, one would then discover with other properties that the combination of other properties does not match minerals in the non-metallic group. A wrong determination of luster will be apparent, thus sending one to the other category for further assessment.

Materials for test

- Mineral sample
- Overhead light

Procedure for the reflection test

- **Hold** the sample to orient it with any planar (flatter) surfaces facing an overhead light.
- **Rotate** the sample back-and-forth to reflect light from a source.
- **Observe** the reflection of light from any flat surfaces.

Possible test results and interpretation

- **Metallic**. As the mineral is turned against the overhead light, we observe a flash described as that from a polished metal surface. We identify this type of reflection as **metallic.**
- **Non-metallic**. As the mineral is turned against the overhead light, we either observe a flash that does not resemble polished metal. We identify this type of reflection as **non-metallic**. For our quick-and-dirty assessment of luster at this time, we don't need to determine the type of **non-metallic** reflection (e.g., glassy, pearly, earthy, etc.).

Procedure for transmission test

- Hold the mineral in front of a light (the brighter, the better).
- Orient the sample and look through the thinnest edge or corner.
- Observe any light passing through the mineral.

Possible test results and interpretation

- *Non-metallic luster*. If the sample absorbs and transmits any light, indicated by a glow, (e.g. best to find a thin edge), then the mineral is non-metallic.
- *Metallic luster*. If the sample reflects all light in a mirror-like (not glassy) fashion, then mineral **may be** (*but might not be*) metallic. Extreme caution about your conclusion is indicated here.

Ready For A Practice Quiz?

Click image below, or this link - Practice Quiz - Luster.

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3: ORIGIN DETERMINATION

3.1: Origin Determination

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3.1: Origin Determination

Introduction

Collectors of gemstones and minerals often attach great importance to a gemstone's provenance or country of origin. In "A Question of Origin," according to Mr. Richard W. Hughes, (1990, [2], n.p.), formerly, there was no method of geographical origin determination for colored gemstones or diamonds; a gemstone or diamond's "mine-type" was strictly based on overall quality and appearance or color. For example, a ruby of an "intense, highly fluorescent red" was sometimes called "Burma-type," or "Burma-like," even when the ruby was not mined in Burma. In the 1940's and 1950,'s the GIA, along with others in the gemology field, developed the system of quality analysis for diamonds; and mine-types were no longer used in describing diamonds. Some examples of the mine-types used to describe diamonds are "Golcondas" or "Premiers," and several others. Also, during the '40's and '50's, studies initiated by Dr. Eduard J. Gübelin, proved that it was possible to identity a gemstone's geographical origin and sometimes even the exact mine it came from based on the gemstone's inclusions rather than using its overall appearance (Hughes, 1990, A Question of Origin, [3], n.p.).

Father of Origin Determination: Dr. Eduard (Edward) J. Gübelin

> "To anyone who loves gemstones and rejoices in their radiant, coloured and dazzling exterior beauty comes involuntarily the desire to be able to peep into their interior. (...) Only the message from their interior – their inclusions, the documents of their evolution in the womb of the earth – renders them vital, natural and precious. The existence of these inclusions is a part of the value and the charm with which gemstones are favoured. (...) These have, moreover, the inestimable advantage that they can 'speak' to anyone who will hear and understand the language of the gemstone's interior décor. They tell of a place and time of the stone's origin, they grant glimpses into the distant past and creative forces of our planet. (...) They are, beyond that, a prosaicly valuable tool for jewelers and gemmologists who with their help can detect frauds and determine the provenance from a certain country and sometimes even from a certain gem mine. (...) The inclusions – the inner life – of gemstones are their speech: it is lyrical, dramatic, rational or aesthetic according to whether one understands how to listen to it and what one wishes to hear."
> Dr. Eduard J. Gübelin - (Gübelin Gem Lab, Ltd., n.d., "Legacy of Dr. Eduard J. Gübelin," [1], n.p.)

The late Dr. Eduard J. Gübelin of Lucerne, Switzerland "devoted his life and career to unveiling the mystique of gemstones and was recognized as the authority on inclusions in gemstones. His great knowledge of mineralogy and the jewelry business combined with his passion and admiration for gemstones made him one of the founders of modern gemology and the father of gemstone origin determination (Gübelin Gem Lab, Ltd., n.d., "Legacy of Dr. Eduard J. Gübelin," [4], n.p.)." During his 70-year career, Dr. Gübelin collected over 5,000 rare and commercial gem specimens, which included organic gemstones, from different localities. He began to determine the origin of gemstones by systematically documenting, classifying, and categorizing gemstone specimens he collected from the mines and locations he toured. Based on the microscopic features or inclusions in the gemstones he established a "strict characterization" of gem deposits. "His concept is based on the comparison of a gemstone of unknown origin with gemstones of known origin; by determining their similarity, and the degree of resemblance of gemstones from different mining sources (Gübelin Gem Lab, Ltd., September 2006, *A Holistic Method to Determining Gem Origin,* [5], p. 122)." In the early 1950's, Dr. Gübelin's gemological studies led to an increase in the interest of different mining sources, the science of gemstone geographical origin determination, and gemological laboratory country-of-origin reports which are used by every auction house today.

Mine Production

Mines produce a wide variety of gemstones, usually of low to medium quality, with the finer gemstones forming only a "tiny fraction of the whole production," including those which are found at the most prestigious sources. The precious gemstones, ruby, sapphire, and emerald, may show price variations and some command premium prices based on their provenance since part of the colored gemstone marketing and branding concept includes origin, even though these stones may not always be of high quality. "Origin" should not be used to reflect a certain quality of colored gemstones, nor should it be used as a description of a color type (Hughes, 1990, A Question of Origin, [6], n.p.). Today, some top-quality gemstones from recently discovered deposits, such as the sapphires found in Madagascar, with similar geology as their highly-valued gemstone counterparts, are not only

impressive, but are also found in remarkable sizes; yet, since they are not from a well-known or prestigious source, they are accepted as nothing more than beautiful stones by most in the trade (Gübelin Gem Lab, Ltd., July 2006, *The Roots of Origin Determination,* [7], p. 66). With the exception of spinel, tourmaline, pink topaz, and alexandrite, geographic origin determination is not yet available for other gemstones.

Origin Determination

Recognized for being largely responsible for the development of the science of origin determination pioneered by Dr. Eduard J. Gübelin, Gübelin Gem Lab, Ltd., determined that it is a "key requirement" for gemological laboratories to have access to an authentic and complete collection of reference stones, which have had their gemological properties properly analyzed and fully documented, and their geologic-genetic environment is known (Gübelin Gem Lab, Ltd., July 2006, *The Roots of Origin Determination,* [8], p. 69). The reference stone collection must contain a sufficiently high number of samples from commercially relevant mining areas and deposits worldwide which include reference stones from exhausted mines or deposits where production has ceased. It is usually very rare to be able to collect samples directly from the host rock in the mine. The research field gemologist collects sample stones from mining areas and deposits worldwide by adhering to strict criteria and guidelines for collection. Extreme care and caution are recommended before samples can be incorporated into a reference collection because receiving stones from a source other than one claimed can have disastrous results. The process and method which the sample stones are collected is fully and properly documented; and then, are compared with the analytical data from the reference collection, or gemstones from a known source, such as the mining area, geographic location, or country, to determine and confirm the origin of the collected samples. One problem research field gemologists face is that of maintaining a current and reliable population of sample stones. Since new material is being found almost daily, tracking changes of the properties and chemistry of new and old deposit production can be a daunting task (Gübelin Gem Lab, Ltd., September 2006, *A Holistic Method to Determining Gem Origin,* [9], p. 126). For example, the best reference stone population of Ceylon sapphires collected 20 years ago may not be as valid for comparison as recently collected samples might be (Hughes, 1990, A Question of Origin, [10], n.p.). Therefore, gemological laboratories must continuously acquire new information through research that must be repeatedly updated. Samples must be collected and updated from mines that are open or reopen every year worldwide. Some colored gemstone mines or deposits may become depleted or inaccessible due to socio-political complications which can make it quite difficult for the research field gemologist to collect specimens. Providing information on the geographic provenance of a stone is the goal of the origin determination process.

Therefore, "the goal of origin determination is to provide the geographic provenance of a gemstone and can be defined as:

1. the attribution of a stone to a specific geological-genetic environment (or a specific type of deposit) and
2. the attribution of a stone to a mining area, a geographic locality, or country (Gübelin Gem Lab, Ltd., July 2006, *The Roots of Origin Determination,* [11],p. 69)

Corundum

Rubies and sapphires belong to the corundum mineralogical family. At one time, corundum was regarded as a rare mineral, until it was realized that it was of more frequent occurrence than once supposed. For example, today, in approximately 20 countries around the world, gem-quality ruby can be found. Corundum is formed in several distinct ways and under various conditions; and the geological environments from which they are formed have a direct impact on the properties and characteristics of corundum (Smith, et al., 2008, Inside Rubies, p. 147).

Source-Type Classification of Corundum

Gemological laboratories are now able to determine the geological localities of corundum by their properties, characteristics, and understanding the genetic environment from which they were formed. "Through years of experience, Mr. Christopher P. Smith, with the American Gemological Laboratories, have proposed a new "source-type" classification for gem corundum that is based on the precept that the geologic environments of their formation give rise to certain distinctive characteristics in which they occurred, as well as an indication of the particular geographic localities from which they may have been found. This system of classification has been given the name, "source-type," as a reference to the broad application of the word, "source." Source-type may not only refer to a geologic source, but may also be indicative of a geographic source as well (Smith, et al., 2009, Corundum – Source Type Classification and Geographic Origin Declarations: Part I, n.p.)."

According to Mr. Christopher P. Smith and American Gemological Laboratories (2008), "this classification has two tiers; the first

tier separates corundum into three groups based on broad geologic formation features. Two of these groups possess what are considered to be “classical” combinations of specific gemological features, which occur in metamorphic and magmatic-related environments. The third group incorporates corundum that possesses combinations of features, properties, and characteristics outside of the two “classical” groups, and may have derived from either a metamorphic or magmatic-related deposit (Inside Rubies, p.147).” “The second tier of the classification system subdivides each of these three groups into four categories or “types,” Types I-IV, based on their dominant inclusion features and supported by various other analytical techniques and data from advanced analytical techniques. Combinations of these types may also occur when multiple features are encountered in a stone (Smith, et al., 2008, Inside Rubies, p. 148).”

“The source-type classification of corundum is also comparable with certain quality categories of rubies and sapphires already recognized by gemologists and the colored stone trade. It provides a practical parallel for such groupings, thereby permitting it to be used by gemologists, wholesale and retail trade, and even consumers. It may also be used to provide better clarity for the trade and consumers when used to complement traditional geographic origin reports or declarations (Smith, et al., 2009, Corundum – Source Type Classification and Geographic Origin Declarations: Part I, n.p.).”

Gemstone Formation

The knowledge of a gemstone’s origin provides vital information on the geophysical processes under which it formed below the Earth’s surface. Traces of other minerals, or inclusions, found in a gemstone, provide information about whether it is natural or synthetic and may provide possible clues of its geographical or geological origin. In the gemstones of the same species which are found in different localities, such as the garnet species, the minor and trace elements are different, or incorporated differently, and may also be used as a tool for determining geographical or geological provenance. A gemstone’s gemological and mineralogical properties are controlled directly or indirectly by the environment in which it is formed. “The most relevant factors during natural gemstone formation are: 1) the nature of the host rock, 2) the nature of the host rock and the “interactive events” between the host rock and nearby rock units, such as exchange reactions involving the migration of fluids, thus introducing or taking away chemical components necessary or unwanted for the growth of a gemstone, 3) temperature and pressure conditions, and 4) composition and nature of solutions/liquids responsible for the dissolution, transport, and precipitation of the chemical components involved in crystal growth (Gübelin Gem Lab, Ltd., July 2006, *The Roots of Origin Determination,* [12], p. 66).”

Characterization of Gemstone Properties

The provenance of some colored gemstones is possible “because the full range of properties of a gemstone measured and observed in the gemological laboratory reflect the specific conditions of its genetic background during the natural crystallization process and are a direct consequence of the geological-mineralogical conditions of the surrounding host rock before, during, and after the growth of a crystal (Gübelin Gem Lab, Ltd., July 2006, *The Roots of Origin Determination,* [13], p. 69).” Origin determination is more reliable when a gemstone has a great number of individual and characteristic properties, such as its inclusions, growth structure, and physical and chemical properties that are clearly distinguishable from gemstones of the same locality or all other localities. These characteristics should not only positively identify a gem’s origin, but, should also eliminate other possibilities of origin. Gemological research laboratories use similar methods and processes for gemstone country-of-origin determination, such as using customized software, which allow for the processing and evaluation of observations, as well as updating current reference source information. Gemological analysis by a gemological laboratory may result in 10 to 50 observations of a single gemstone, although, some gemological laboratories use simpler methods of observation for origin determination. Some labs or gemological institutions have implemented a “phenomenological classification of gemstones in order to describe certain types of appearances of gemstones (Gübelin Gem Lab, Ltd., September 2006, *A Holistic Method to Determining Gem Origin,* [14], p. 126).” The origin determination process provides information on the geographic or geological provenance of colored gemstones based on data compiled during extensive gemological testing methods which should be non-destructive or at least “quasi non-destructive.” For example, LA-ICP-MS, which employs a laser ablation method, leaves a small crater of up to 200 microns on the surface of a gemstone. “The most important gemological-mineralogical criteria used for the characterization of gemstones are:

1. Inclusion features such as growth features, natural cavity fillings such as fluid inclusions (must not be confused with fillings of fissures and open cavities due to man-made treatments), and solid inclusions:
2. High-temperature enhancements will provoke the thermal alteration of most mineral inclusions and may complicate the origin determination process.
    1. It should be noted that the “study of inclusions is also a relatively new science; there are many gemstone inclusions that have yet to be identified and catalogued; and much to be learned about inclusions (Hughes, 1990, A Question of Origin, [15], n.p.).”

3. Chemical “fingerprinting” such as minor, major, and trace elements:
    1. Minor and trace elements often determine the difference between a common mineral specimen and a gemstone; these trace elements are also often responsible for the color of gemstones.
    2. The incorporated minor elements depend on local geological conditions, such as temperature, reduction-oxidation reaction, and chemistry.
4. Optical properties including birefringence and refractive indices
5. Infrared characteristics
6. Luminescence behavior (Gübelin Gem Lab, Ltd., July 2006, *The Roots of Origin Determination,* [16] p. 68).”
7. Spectral fingerprinting:
    1. UV-ViS-NIR-range: Approximate spectral ranges used in gemology:
        - Ultra-violet: 280-390 nm
        - Visible range: 390-780 nm
        - Near Infrared: 780-1400 nm

Techniques Used for Origin Determination

Origin determination research with modern gemological tools may provide even further information to distinguish gemstones from different localities. Some of the laboratory tests and equipment used for origin determination by some laboratories are:

1. **Optical analysis by microscope**
    - The gemological microscope is an invaluable tool in the laboratory. By using illumination techniques, the internal characteristics of a gemstone can be examined with the microscope to detect whether a gemstone is natural or synthetic by observation of the gemstone’s inclusions and detect many gemstone treatments.

2. **Spectroscopic analysis in Ultra violet-Visible-Near Infrared (UV-ViS-NIR)**
    - This instrument analyzes a full range of spectrum, from the ultra-violet to near infrared. A gemstone absorbs light at a different range depending on its natural or treated trace elements or color centers. The UV-Vis-NIR technique is used to:
      - Provide the geological environment and origin of gemstone
      - Determine the origin of color of a gemstone
      - Determine the source of corundum from different localities
      - Identify unknown gem materials
      - Type classification of diamonds
      - Differentiate natural from synthetic materials
      - Detect irradiation or heat treatment of gemstones

3. **Raman spectroscopic analysis using a Raman spectroscope**
    - This is a light-scattering and non-destructive technique which allows for the identification of inclusions in a gemstone by comparing a gemstone’s spectrum to a mineral database for identification of a gemstone. It shoots a laser beam at the gemstone sample and then measures the weak light emitted to measure the spectrum of the Raman Effect. Since each gemstone has its own distinguishing spectral pattern, the Raman Effect can be used as a tool of identification. The Raman can be used to:
      - Identify liquid, solid, and gas phases
      - Fingerprint inclusions
      - Separate naturals from synthetics
      - Identify a gemstone’s provenance, and in some cases, the exact mine from which a stone was obtained

4. **Spectroscopic analysis by Fourier Transform Infrared Spectrometry (FT-IR)**

5. **Chemical analysis by Energy-dispersive X-ray Fluorescence (ED-XRF)**
    - The ED-XRF, a non-destructive spectroscopic technique, uses an x-ray beam that illuminates the gemstone sample. This energy causes the material to emit x-rays and is used for:
      - Trace metal and transition metal determination
      - Determining chemical composition of a gemstone

- Detection for a number of gemstone enhancements
- Revealing whether staining or chemical impregnation has occurred in gemstones
- Differentiating freshwater from saltwater pearls
- Determining the origins of corundum and alexandrite
- Determining the geological environment in which stones were formed

6. **Chemical analysis by Laser-induced Breakdown Spectroscopy (LIBS)**
   - The technique, LIBS, also known as Laser Spark Spectroscopy (LASS) or Laser-Induced Plasma Spectroscopy (LIPS), is used especially for:
     - The analyses of major, minor, and trace elements
     - The identification of beryllium-diffused heat treatment in corundum
     - Detection of beryllium concentrations and lithium in gemstones accurately down to 1 to 10 ppm level which requires that calibration standards must be created for each substance tested for accurate testing results

7. **Chemical analysis by Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS)**
   - The MS identifies and quantifies elements in terms of mass and charge and can detect 65 elements and their relative amounts, even when present in only a few parts per billion. The ICP-MS is useful for determining the origin of emeralds that are formed comparatively "locally" in geological stratus and when used with FT-IR and Mössbauer spectroscopy. The LA-ICP-MS technique uses a laser beam, which leaves a small crater of up to 200 microns on the surface of a gemstone, which vaporizes an extremely small sample of a gemstone. The ablated sample is carried by a stream of inert gas, usually argon, into a high-temperature field, causing the ionization of atoms and the dissociation of molecules. It is used for the:
     - Detection of gemstone treatments
     - Origin determination of gemstones
     -Chemical analysis of corundum that can also detect Beryllium

8. **Surface analysis by SEM (Scanning Electron Microscope)**
   - The SEMs technique, with additional attachments, can obtain elemental analysis. Polished specimens give a better result, since in rough specimens the variations are due to surface rather than the actual structure. In most cases, the samples have to be coated with a layer of silver or gold for more accurate results. SEM uses high magnification for examination of surface and submicroscopic surfaces. It is useful for:
     - Identification of gemstones
     - Origin identification of gemstones
     - Identification of treatments, such as the glass fillings in ruby

9. **Isotope analysis (destructive)**
   - Isotope analysis (destructive) of corundum by using a databank for compiling the oxygen isotope concentration ratios for corundum of alsi basaltic-type places which requires access to the primary deposit to confirm the origin. Important and necessary tools to identify provenance of gemstones are ED-XRF, Raman spectroscopy, and ICP-MS.

Challenges for Origin Determination

How do laboratories determine the country of origin if gemstones are formed in similar genetic environments or geological and mineralogical conditions, yet, their geographic regions are located great distances apart? For example, sapphires originating from the Sri Lankan and the Kashmir region have similar or overlapping gemological properties, which make determining a separation between the sources almost impossible. With the scenario of gemstones having very similar properties which are from different locations, instead of searching for one diagnostic feature to separate the sources, a comprehensive view of the gemstones is considered, such as the identification and description of inclusions, analysis of chemical elements, and spectral properties. "Evaluation and interpretation of the observed features, combined with additional advanced analysis," may allow a laboratory to reach a conclusion on the geographic origin of the gemstones (Gübelin Gem Lab, Ltd, August 2006, *The Limitations of Origin Determination,* [17], p. 62).

There are also various mines and deposits, which are scattered over a geographical location and categorized as a single entity,

such as the Montana sapphires found in the United States, which produce stones which differ not only in color, but also inclusions. Sapphires from the Missouri River mines differ from those found at Yogo Gulch as well as the sapphires found at Rock Creek. Unfortunately, in this case, there is no distinction between the localities of the deposits, even though each of the deposits produces sapphires with differing and distinct characteristics (Hughes, 1990, A Question of Origin, [18], n.p.).

Laboratories that provide origin reports are vulnerable when new gemstone treatments, synthetics, or newly discovered material enter the market. It is necessary that the laboratories are able to research new finds by visiting the new deposits or mines, and research new treatments and synthetics possibly before they enter the market. One scenario laboratories may face is when a consumer's colored gemstone is sent to 2 different laboratories for origin determination with differing results of the stone's provenance from each of the labs. The consequences may be dire for the consumer. For example, at the May 2009 ICA Congress Speech of Dr. Adolph Peretti, Dr. Peretti shed light that the "misinterpretation of a gemstone's origin may possibly provide a gem dealer with a huge premium. If a consumer sends the gemstone, for example, a ruby, to one laboratory for origin determination, which declares the ruby of Burmese origin, and then the consumer sends the ruby to a different laboratory, which concludes that the ruby is of Vietnamese origin, the consumer may lose the amount of money the dealer made with his initial premium. The ruby mentioned in the hypothetical scenario was from a new deposit and had not been examined by laboratories for origin testing before it entered the market and was sold to a consumer (ICA Congress Speech of Dr. Adolph Peretti, May 2009, "Research report summaries on the origin and treatments of valuable rubies from Tanzania and tourmalines from Brazil and Mozambique," [19], n.p)." However, the percentage of these conflicting origin reports is relatively small. Misidentifying the origin a gemstone is usually an unfortunate consequence of the lack of funding and research needed to provide accurate origin determination, but, it is a necessity that labs are able to ensure the integrity of their gemstone country-of-origin reports. If the origin for a gemstone cannot be determined, laboratories will state that "no origin" could be determined for the gem in question. For example, when a laboratory tests a stone for its geographical location, but findings of the gemological test results and observations are insufficient, or uncertain, the opinion of the gemstone's origin should not be given.

Dr. Peretti discussed another challenge for laboratories which provide origin reports are the problem encountered in the gemstone market which involves the provenance of Paraiba Tourmaline. Paraiba Tourmaline, originally discovered in the state of Brazil in 1989, is a copper-bearing tourmaline of greenish-blue color and the most valuable tourmaline in the world. The recently discovered copper-bearing tourmalines from Mozambique, as well as those from Nigeria, are being called "Paraiba Tourmaline," by some laboratories and gemstone dealers, regardless of their origin. "Comparison of statistics of copper-bearing tourmaline from Mozambique and Brazil show that different colors and sizes are found from both origins. In general, copper-bearing tourmalines from Mozambique have more color varieties, while tourmalines from the state of Brazil are more color intense at equal sizes." A "non-educated" consumer may believe he or she is purchasing a Paraiba Tourmaline from Brazil, when actually in reality, the tourmaline is from Africa. Since a huge price difference exists between the origins of copper-bearing tourmalines, with the Brazilian Paraiba Tourmalines commanding much higher prices, this dilemma "may lead into legally critical situations (ICA Congress Speech of Dr. Adolph Peretti, May 2009, "Research report summaries on the origin and treatments of valuable rubies from Tanzania and tourmalines from Brazil and Mozambique," [20], n.p)."

Benefits of Origin Determination

At the 2007 ICA Congress Lab Session, Mr. Christopher P. Smith discussed with attendees that gemstone geographic origin determination is not "an exact science" and is still in its infancy. Also attending the session, Mr. Vincent Pardieu stressed the necessity and importance gem laboratories must not only strive to keep up with technology related to treatments and synthetics; but also research new gem deposits to keep up with the growing demand for origin determination reports. (ICA Congress Lab Session, May 2007, "Labs Tackle Question of How to Help Industry, Build Consumer Confidence at ICA Congress," [21], n.p.). With the 2008 United States of America government ban on the importation of rubies from Burma into the US still in effect, county-of-origin determination, particularly for corundum, has additional importance to the trade as well as consumers. Origin reports may have a serious political purpose when they are used to prevent the unregulated sale (smuggle or launder) of "conflict gemstones" (Lesney, 2001, Precious Provenance, [22], n.p.). Thus far, the attempt to implement a system, similar to the Kimberely Process for diamonds, to ensure that a ruby is not from Burma, has been unsuccessful since the "majority of ruby-producing areas are highly decentralized. Other ruby deposits discovered in Africa, such as the beautiful and usually unenhanced Winza ruby, recently discovered in Tanzania Country, show promising alternatives for sources which may produce gem-quality stones. In 2002, Columbia Gem House of Vancouver, Washington, in the United States, implemented a mine-to-market promotion to bring rubies into the U.S. from Malawi by developing a local mining industry and partnering in community and social developments (Smith, et al., 2008, Inside Rubies, p. 141)."

Understanding the genesis of gemstones helps in the determination of their geographical origin, thus improving prospecting strategies for mining gemstones, such as corundum, which could also be used as a method for controlling the trading circuits. The need for 3rd party certification for gemstones from gemological laboratories, including country-of-origin reports, can also help

support and grow the industry. Consumers of gemstones not only want to know the gemstones they purchase are being identified properly and that they are reasonably priced, but, also, they also want to be reassured that the gemstones are from conflict-free sources. Laboratories hope to build and sustain consumer confidence through the issuance of colored gemstone country-of-origin reports. Today, consumers purchase over 50% of gemstones via television shopping networks and the internet which has forced traditional jewelers to reexamine how they sold gemstones. Jewelers are now more likely to provide gemstone provenance with gemstone identification reports for their high-end gemstones. Laboratories also work closely with those in the trade to be able to provide origin reports and certificates for gemstones at a reasonable price, as well as educating people in retail to speak confidently about the gemstones they sell (ICA Congress Speech of Dr. Adolph Peretti, May 2009, "Research report summaries on the origin and treatments of valuable rubies from Tanzania and tourmalines from Brazil and Mozambique," [23], n.p).

Most gemological laboratories invest a certain amount of their resources in scientific research activities, which is usually used "in-house," but, is also shared with the gemological and geological communities through research publications. An effective way of obtaining first-hand access to scientific results is through the cooperation of researchers and research organizations (Gübelin Gem Lab, Ltd., September 2006, *A Holistic Method to Determining Gem Origin,* [24], p.126).

Intellectual Requirements

Origin determination requires a thorough understanding of the geological processes. The "interpretation of small-scale gemological observations requires constant verification with the scientific models of large-scale geological environments (Gübelin Gem Lab, Ltd., September 2006, *A Holistic Method to Determining Gem Origin,* [25], p.126)." It is recommended that most gemologists at a gemological laboratory, who are involved in origin determination, hold a degree in the earth sciences, such as mineralogy, petrology, crystallography, geology, or a related field. To be able to successfully tackle the challenges of origin determination, this academic foundation should be complemented with "solid" gemological training and several years of experience in a gem lab. The analysis of gemological properties and interpretation of the resulting data and observations alone exceed the level of knowledge taught in standard gemological training (Gübelin Gem Lab, Ltd., September 2006, *A Holistic Method to Determining Gem Origin,* [26], p.126).

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4: THE CHEMISTRY OF GEMSTONES

4.1: Chemistry of Gemstones
4.2: Isomorphous Replacement
4.3: The Chemical Classification of Gems and Minerals

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4.1: Chemistry of Gemstones

An **element** is a substance that can not be separated into a simpler form of matter by ordinary means. An element may be a solid, liquid or a gas.
Some common elements are carbon, gold, copper, iron, oxygen, silicon, etc.

An **atom** is the smallest part of an element. It is the smallest, indivisible particle of a chemical element. Each atom consists of negatively charged electrons and positively charged protons. There are a similar number of electrons and protons to produce an electrically neutral atom.

An atom cannot be subdivided by any chemical process.

Basic

Atoms

An **atom** is the smallest part of an element. It is the smallest, indivisible particle of a chemical element which still possesses all the properties of that element. Each atom consists of negatively charged electrons and positively charged protons as well as uncharged neutrons (with the exception of hydrogen). There are a similar number of electrons and protons to produce an electrically neutral atom.
Protons and neutrons reside in the nucleus while electrons spin around the nucleus in orbitals (not orbits).

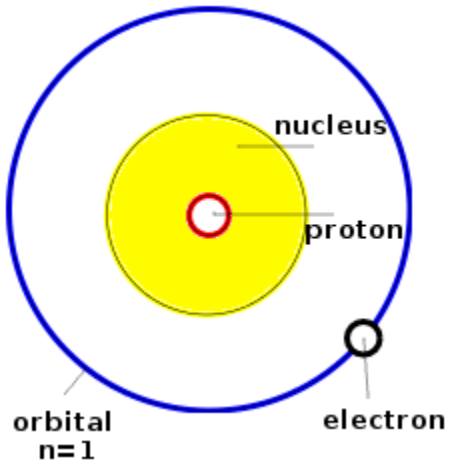


Figure 4.1.1*: Bohr model of hydrogen (without any neutrons)*

Danish physicist Niels Bohr was the first to make a diagram to visualize the components of an atom. The image on the left is such a diagram, drawn to represent a hydrogen atom. Hydrogen is the only atom that does not have a neutron in its nucleus (this is actually only true for the hydrogen *isotope* protium). It has one positive charged proton in its nucleus and one negative charged electron spinning around the nucleus.
As there are as many positive as negative charges in the atom, the total charge is neutral.

The orbitals around a nucleus are numbered 1 through 7 and serve as energy levels. Formerly they were named K, L, M, N and O shells. One can still use the alphabeticals but the numerical values are preferred.

Every orbital (or energy level or shell) can hold a specific amount of electrons. For n=1 that is 2 electrons and for n=2 that is 8 electrons. One can easily calculate the **maximum** number of electrons a specific shell can hold by using the formula: $2n^2$.

With n=1, you will get 2 x $(1)^2$, or 2 x 1 = 2 electrons.
With n=2, that makes 2 x $(2)^2$, or 2 x 4 = 8 electrons etc.

> **Note**
>
> For general gemological purposes, we are not concerned much with protons and neutrons, just electrons (but one should be aware of them).

Electrons fill from the ground up, which means that the lowest shells are filled first before the next shell can get an electron. Electrons tend to travel in pairs and when this happens they are referred to as *paired electrons*.
In the gallery below, the atom helium has 2 electrons spinning around a nucleus of 2 protons (and 2 neutrons), they fill the first shell completely. Lithium has 3 electrons and since three electrons will fit in the first shell, the third occupies the next level, which is n=2. Beryllium has 4 electrons, thus 2 electrons in n1 (the maximum) and 2 electrons in n2. Finally the 5th element boron has 5 electrons, so 3 electrons travel in n2.

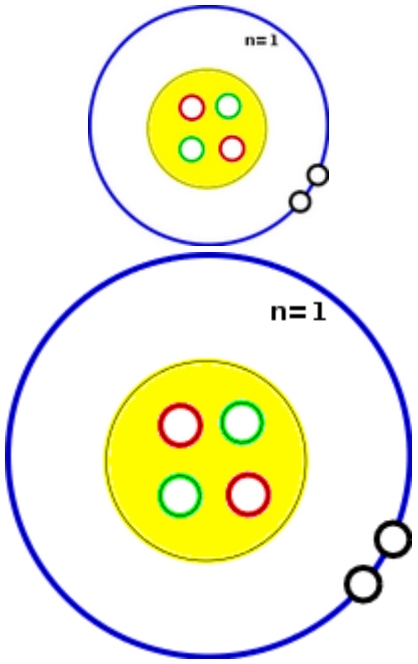


Figure 4.1.2*: Helium*
2 protons, 2 neutrons and 2 electrons

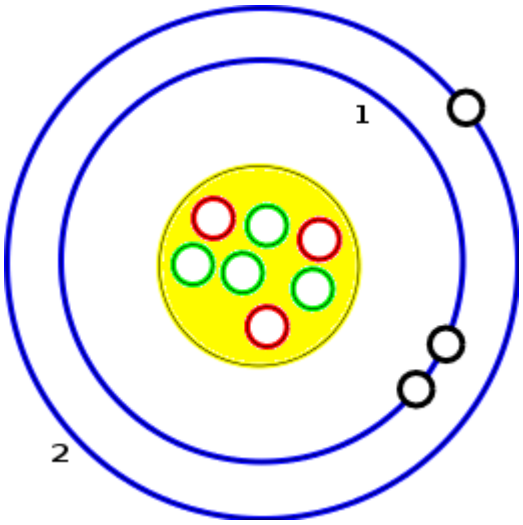


Figure 4.1.3*: Lithium*
3 protons, 4 neutrons and 3 electrons

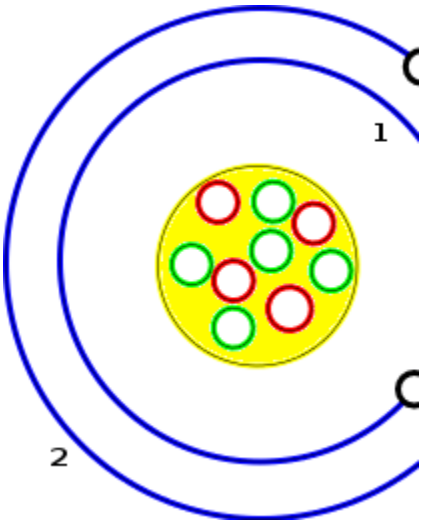
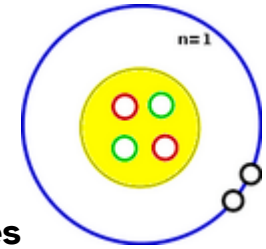


Figure 4.1.4*: Beryllium*
4 protons, 5 neutrons and 4 elect



Molecules

Atoms of elements can combine together to form tiny fractions of new substances known as compounds. A molecule is defined as the smallest fraction of a substance, consisting of two or more elements chemically combined and defining the substance's composition and chemical properties.

Advanced

Atoms and the quantum theory

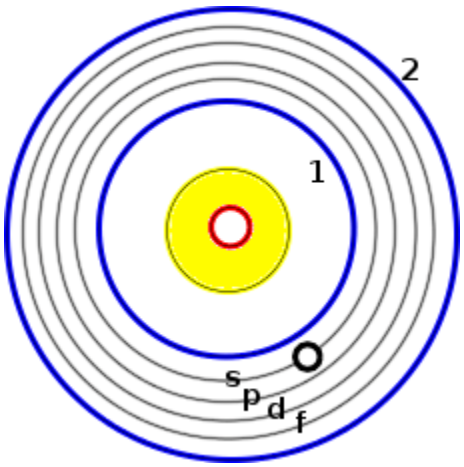


Figure 4.1.6*: Simplified Bohr model with subshells*

Although the basic Bohr model with its single energy shells works well most of the time, it cannot be used to understand more complex electron configurations and/or magnetism.
According to the Pauli exclusion principle, no two same particles can be in the same atomic energy state. This brings us to the core of the quantum theory (when electron structure of atoms are described) which relies on 4 quantum numbers:

- The principal quantum number (*n*)
- The angular momentum quantum number (*l*)
- The magnetic quantum number (m_l)
- The spin quantum number (m_s)

In the image on the right, a crude example is drawn which shows 4 subshells in the principal shell (n=1). Although it resembles the hydrogen atom, it is only for illustration purposes; not a real situation, as hydrogen has only one subshell (s).

Principal quantum number indicates the energy level of an atom with lower levels having lesser energy and it is expressed in *n* (also know as the K, L, M, N, O etc shells). There is a maximum of 7 shells and each shell is described as n=1 through n=7.

Angular momentum quantum number (or azimuthal quantum number) can have an integer number of 0 through 3 (although in theory it can go up to 6). These are known as subshells of the energy levels.
Each principal quantum number (or energy level) can have a certain amount of subshells identified by: 0 - (n-1). For hydrogen (with n=1) this will be 0 through 1-1 = only 0. For an atom with n=2 as the highest energy level this will be 0 - 2-1, so 0 an 1. In electron configurations they are named s, *p*, *d*, and *f* according to spectral readings.

These alphabeticals correspond with the subshell numbers:

- 0 = s
- 1 = p
- 2 = d
- 3 = f

Magnetic quantum number has to do with the orientation of the orbital in a magnetic field and takes the integer values -l to +l, so if l=2 (the same as l=d) the magnetic quantum number (m_l) can be -2,-1,0,1 and 2.
These "orbitals" all have the same energy and electrons fill them not in pairs if possible. Only when all are filled with 1 electron the filling goes on until they have paired electrons. These orbitals can hold a maximum of 2 electrons each (Pauli exclusion principle).

Spin quantum number describes how the electrons spin in the energy levels. It can be either 1/2+ or 1/2- (also referred to as upspin and downspin) and one can visualize this as the planet Earth spinning around its axis (clockwise or counter-clockwise).

When two electrons are in the same energy level, one will have upspin and one will have downspin, balancing it to zero.

These spins are what causes magnetism, like in iron for instance. When the energy levels are filled, they fill up with one electron at a time, all having the same spin. When many (unpaired) electrons have the same spin they will act together as a more powerful magnet than when there would only be one unpaired electron (which would be a tiny magnet).

Valency

The valency of an element is determined by the number of its atoms which will combine with, or replace, one atom of hydrogen. It can be observed that some elements will have different valencies in different compounds. For example, the compound FeO (ferrous oxide) is divalent and Fe2O3 (ferric oxide) is trivalent.

Electronic Configuration of Atoms

Properties of an element, chemical compounds and the formation of crystals depend a great deal on the disposition of electrons and their interaction. The electrons circle the nucleus in all directions, like a cloud. The radius of the average of their movements is defined as a shell or energy level. These shells will remain at a predictable level which is determined by quantum mechanics. Each shell contains only a given number of electrons. There is a maximum of 2 in the innermost shell (known as the K shell or n=1), and 8 each in the second shell (known as the L shell or n=2). There are 18 each in the third shell (known as the N shell or n=3) etc following the $2n^2$ rule.

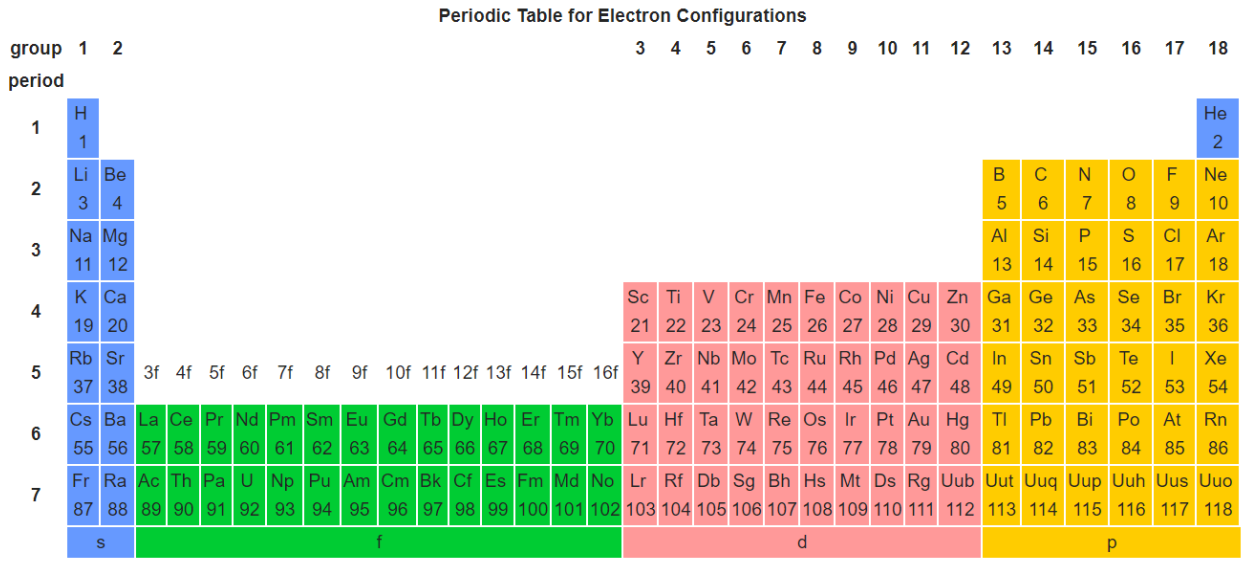


Figure 4.1.7*: Periodic Table for Electron Configurations*

Atomic Number

Each of the chemical elements is made up of like atoms, also known as the atomic number. They all have the same number of protons. Hydrogen (atomic No. 1), has one proton and one planetary electron. The heaviest naturally occurring atom, uranium, has 92 protons and 92 electrons.
Element 112 was discovered on 9th February 1996 in Darmstadt, Germany. The identified isotope currently is the heaviest atom ever produced by man and has an atomic mass of 277, that is, 277 times heavier than hydrogen.
Except for hydrogen, all the other nuclei of atoms contain neutrons, varying from 2 in the case of helium to 146 in the uranium atom. The **atomic weight** of an element is the weight of the protons and neutrons, which form the nucleus of the atom. If an atom gains or loses one electron, it ceases to be electrically neutral and becomes what is known as an ion. The gaining of electrons produces a negatively charged ion, known as an anion. Loss of electrons results in a positively charged ion referred to as a cation.

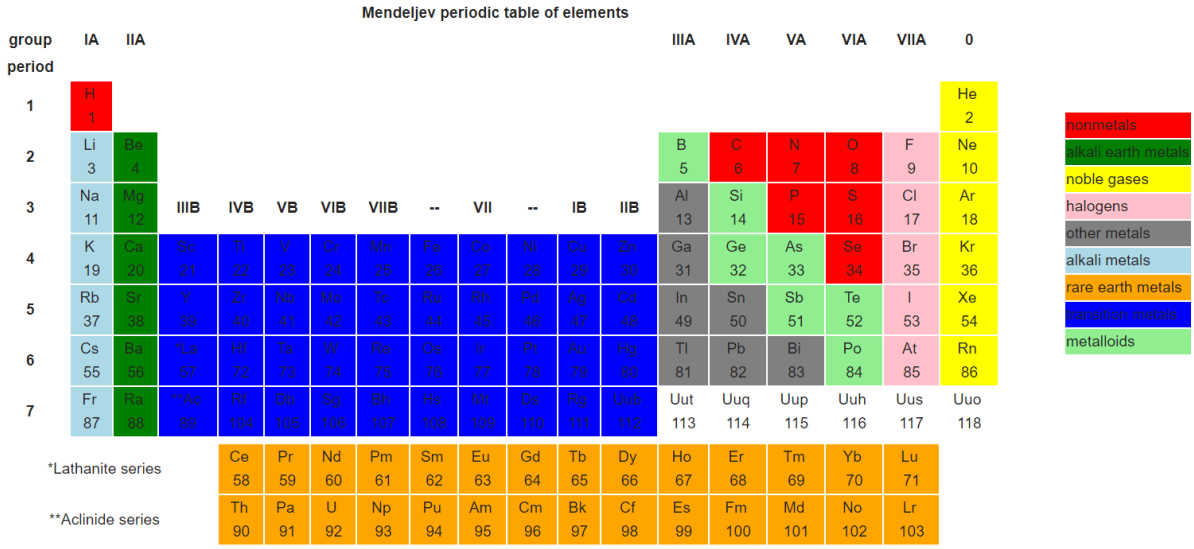


Figure 4.1.8*: Mendeljev periodic table of elements*

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4.2: Isomorphous Replacement

Isomorphous replacement is the replacement of certain elements in a gemstone by another element of the same valency, without the gemstone changing in form. The word *isomorph* comes from *iso* (same) and *morph* (form). Thus, although the chemical makeup of the gemstone changes, the crystal form does not. The favorite gemstone variety used to explain this phenomenon is the garnet group.

Basic

When explaining isomorphous replacement, the garnet group is most suitable for illustration.

One can divide the garnets into two main groups (refer to garnet for a detailed explanation).

1. Pyralspite (pyrope - almandine - spessartine)
2. Ugrandite (uvarovite - grossular - andradite)

Each member of these two groups has an "ideal" chemical makeup. For instance, for the pyralspites this will be:

- Pyrope - magnesium aluminum silicate
- Almandine - iron aluminum silicate
- Spessartine - manganese aluminum silicate

In the pyralspite list above, the first element mentioned changes from member to member. However, in nature one will never find a pyrope garnet with such a pure chemical makeup. Instead, during growth other elements -- present in the melt from which the pyrope grew -- were mixed in.

When iron (as seen in almandine, above) is mixed in during the growth of a pyrope garnet, one would get a magnesium-iron aluminum silicate. Part of the magnesium content in the pyrope was replaced by iron.

It is the amount of magnesium/iron content that defines the distinguishing line between pyrope and almandine. When there is an abundance of magnesium in the chemical makeup, it is a pyrope. When iron is dominant, it is almandine garnet.

When the mix is somewhere in between, we name it pyrope-almandine garnet. (These mixtures may have some exotic names, such as rhodolite, that are not of importance here). It should be noted that the boundaries where it is a pyrope or where it is an almandine is under heavy debate.

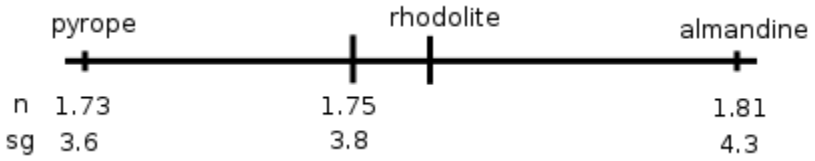


Figure 4.2.1*:* Timeline of isomorphous replacement of magnesium/iron in pyrope-almandine

As can be seen in the "timeline" image showing the replacement of magnesium with iron, the physical and optical properties of the gemstone change as well. In this example (pyrope-almandine), note that the index of refraction and the specific gravity increase.

In the above example pyrope (magnesium) and almandine (iron) are two "end members" with a whole range of possible values in between, depending on how much magnesium or iron is present in that specific gemstone.

Figure 4.2.2*:* Pyralspite triangle

One could draw likewise "timelines" between pyrope and spessartine, or between almandine and spessartine. From the "pyralspite triangle", it is obvious that between the 3 "end members" of the pyralspite group every value is possible and that physical and optical properties vary at great length.

The latter is very important to remember when testing garnets, as no value will be the same. Instead, values will fall within a "range". In fact, there may even be a mix of all three of the end members.

Likewise, timelines and a triangle can be drawn for the ugrandite garnets, and there may even be elements of the pyralspite present in the ugrandite garnets. The possibilities are almost limitless.

The habit of the garnet, however, does not change.

> **Note**
>
> The mixing of elements occurs at the time of formation of the gemstone, not afterward. So the isomorphous replacement does not happen after crystallization.

Valency in isomorphous replacement

The chemical formula of garnet is $L_3M_2(SiO_4)_3$, which means that the first element has a valency of 2^+. Elements with the same valency can easily replace each other to form new chemical bonds, as in the case of garnet. One should not confuse the presence of trace elements with isomorphous replacement. Trace elements are not part of the "ideal" chemical makeup.

Isomorphic gemstones

Besides garnet, there are other gemstone varieties that show isomorphic replacement:

- Garnet
- Spinel
- Olivine (peridot)
- Plagioclase feldspar

Advanced

When two ions are brought together, there is a distance where a force of repulsion abruptly sets in and resists any closer approach. It is convenient to consider the ions as "spheres" in contact, and the distance between their centers is taken as the sum of the radii of the two ions. Anions, such as an oxygen ion, have large ionic radii, whereas cations have radii that are much smaller.

The common cations which enter the structure of crystals are often those with similarly sized radii and can replace each other within the structure without unduly straining the space lattice. This accounts for the phenomenon of isomorphism and isomorphic replacement.

In the garnet and spinel groups, magnesia (MgO) and ferrous oxide (FeO) replace one another extensively. Likewise, alumina (Al_2O_3) and ferric oxide (Fe_2O_3) can easily replace each other within a crystal's lattice. When such a replacement takes place, there can be a significant variation in chemical composition without much affecting the internal structure. This accounts for the fact that, in certain gemstones of the same species, the specific gravity and refractive indices are not constant from specimen to specimen. In some species like garnet, spinel, tourmaline and some members of the beryl group (as beryl, stoppaniite, Indialite, and bazzite), the values for refractive index and specific gravity can vary within wide parameters. This is an important factor to keep in mind when testing gemstones.

Sources

- *Naming Gem Garnets* - W. Wm. Hanneman, Ph.D.

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4.3: The Chemical Classification of Gems and Minerals

The Chemical Classification of Gems and Minerals

Gems can be organized into classes, based on their chemistry.

Table 4.3.1*: Classes of Gems and Minerals*

Class	
Class I: Pure Elements	Metals, all
Class II: Sulfides	Sulfur is the princi
Class III: Halides	Halogen
Class IV: Oxides	Oxygen is the principal anion, includes
Class V a:Carbonates	Carbonate r
Class V b:Borates	Borate radica
Class VI a:Tungstates	Ar
Class VI b:Sulphates	Sulphate ra
Class VII: Phosphates	Ar
Class VIII: Silicates	Silicate groups as anions c

Class I Pure Elements

Table 4.3.2*: Pure Elements*

Class I	
Diamond	

Class II Sulfides

Table 4.3.3*: Sulfides*

Class II	
Marcasite	
Pyrite	
Sphalerite	

Class III Halides

Table 4.3.4*: Halides*

Class III	
Fluorite	

Class IV Oxides

Table 4.3.5*: Oxides*

Class IV	
Anatase	
Brookite	
Chrysoberyl	
Corundum	
Hematite	
Opal	
Quartz	
Rutile	
Spinel	

Class Va Carbonates

Table 4.3.6*: Carbonates*

Class Va	
Aragonite	
Azurite	
Calcite	
Cerrussite	
Malachite	
Rhodochrosite	
Smithsonite	

Class Vb Borates

Table 4.3.7*: Borates*

Class Vb	
Hambergite	
Sinhalite	
Ulexite	

Class VIa Tungstates

Table 4.3.8*: Tungstates*

Class VIa	

Scheelite	

Class VIb Sulphates

Table 4.3.9*: Sulphates*

Class VIb	
Barite	

Class VII Phosphates

Table 4.3.10*: Phosphates*

Class VII	
Amblygonite	
Apatite	
Brazilianite	
Turquoise	

Class VIII Silicates

Table 4.3.11*: Silicates*

Class VIII	
Andalusite	
Beryl	
Iolite (Cordierite)	
Garnet	
Jadeite	
Nephrite	
Topaz	
Tourmaline	(Na^{1+},
Peridot	
Zircon	

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5: CRYSTALLOGRAPHY

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5.2: Crystal Systems
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5.1: Crystallography

Basic

Traditionally, crystallography is the study of crystals and describing them according to geometrical observations. This involves measurement of the crystal faces in relation to their imaginary crystal axes (using a goniometer) and symmetry.
In modern times, crystallography is the study of atom arrangements in solids using x-ray diffraction photography.

Some solids do not have a structured arrangement of atoms—for instance, glass and opal. We refer to these unstructured solids as "amorphous".

A *crystal*:

- is a geometrical solid bound by flat surfaces
- has a regular and symmetrical pattern of atoms ('crystal lattice')
- has physical and optical properties that may vary with direction

An *amorphous* solid has:

- no definite shape ('not crystalline')
- physical and optical properties that remain the same in every direction

Ideally, single crystals can be observed with the unaided eye, however, some crystals are so small they cannot be detected without magnification. Often these small crystals bind together to form a solid and this kind of solid is called *polycrystalline* (poly = many). Formerly, polycrystalline structures were divided into *microcrystalline* and *cryptocrystalline*.

- *Microcrystalline* bodies are composed of small crystals that can be individually observed with magnification (such as a microscope).
- *Cryptocrystalline* substances are made up of such small crystals that a microscope cannot distinguish individual crystals.

Modern microscopes, which can magnify up to 0.3nm, have made the term cryptocrystalline obsolete.

According to observation, we divide crystals into 3 groups and 7 crystal systems.
It should be noted that some gemological institutes (especially USA ones like the GIA) do not consider the trigonal system as a system on its own but classify it as a subgroup of the hexagonal system.

Table 5.1.1*: Crystal Systems*

Crystal system	Group	Axes of symmetry	Planes of symmetry	Center of symmetry	Crystal axes (with dimensions and angles)
Cubic (isometric)	I	13	9	1	3 (a = a = a) (all at 90° to each other)
Tetragonal	II	5	5	1	3 (a = a ≠ c) (all at 90° to each other)
Hexagonal	II	7	7	1	4 (a = a = a ≠ c) (3 at 120°, c-axis at 90° to them)
Trigonal	II	4	3	1	4 (a = a = a ≠ c) (3 at 120°, c-axis at 90° to them)
Orthorhombic	III	3	3	1	3 (a ≠ b ≠ c) (all at 90° to each other)
Monoclinic	III	1	1	1	3 (a ≠ b ≠ c) (a inclining to c, b at 90° to them)
Triclinic	III	none	none	1	3 (a ≠ b ≠ c) (all inclining)

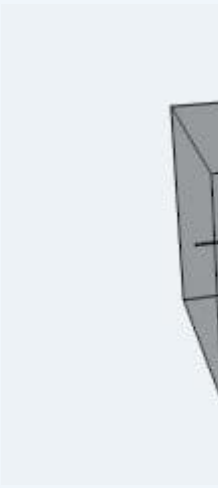
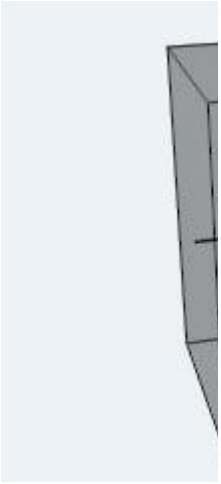
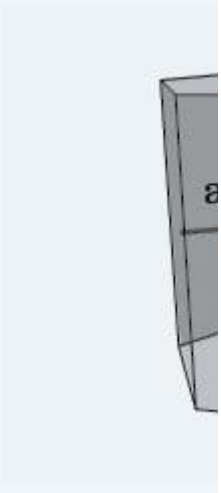
The above mentioned 7 crystal systems are further divided into 32 classes. These classes have different levels of symmetry within each system. The symmetries given above are the highest levels of symmetry within each system.
For example, the trigonal mineral tourmaline has different terminations on the prism ends (due to hemimorphism) and thus will miss one plane of symmetry.

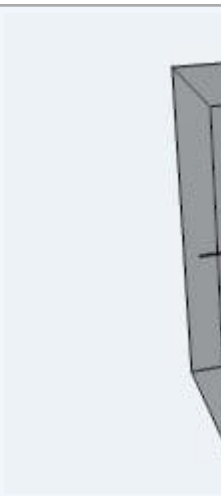
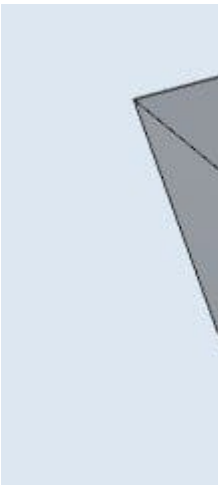
Gemstones in Group I are isometric (same length in all directions of the crystal axes). Gemstones in Group II are uniaxial, and Group III are biaxial.

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5.2: Crystal Systems

Table 5.2.1: *Table of Crystal Systems*

Crystal System	
Cubic The cube is composed of 6 square faces at 90° angles to each other. Each face intersects one of the crystallographic axes and is parallel to the other two.	
Tetragonal The tetragonal system also has three axes that all meet at 90°. It differs from the isometric system in that the C axis is longer or shorter than the A axes, which are the same length.	
Hexagonal In the hexagonal system, we have an additional axis, giving the crystals six sides. Three of these are equal in length and meet at 120° to each other. The C or vertical axis is at 90° to the horizontal axes. Mineralogists sometimes divide this into two systems, the hexagonal and the trigonal, based on their external appearance (see following).	

Trigonal The trigonal system is a subsystem of the hexagonal system according to some institutes, therefore some gem references will list these as hexagonal.	
Orthorhombic In this system, there are three axes all of which meet at 90° to each other. However, all the axes are of different length.	
Monoclinic The above crystal systems all have axes sides that meet at 90°. In the monoclinic system, all the axes are different lengths. The A axis is inclined to the C axis. The B axis is at 90° to them. You can imagine this as a matchbox that slants to one side.	

Triclinic In this system all the axes are different lengths and none of them meet at 90°. You can imagine this as a matchbox which slants to two sides.	

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5.3: Form

Basic

The internal makeup of a mineral is reflected by its ideal outer shape (form). A multitude of forms make the habit of the mineral, although some ideal forms are found in nature as well.

Crystal forms consist of crystal faces that are related by crystal axes. Some faces can enclose a space completely (like a face of a cube) and are named "closed forms". Others need additional faces to help totally enclose a space and these are called "open forms".

Take, for example, one face of a cube (which has 6 faces). That face shape would fit on or match all other faces. Thus, a repetition of that face on all sides of the cube can enclose the space inside the cube (a "closed" form). Now consider a tetragonal prism, which consists of 4 identical prism faces that *cannot* substitute for the bottom and top of the prism without altering the shape of the prism face. To "close" a tetragonal prism, two faces of some other type are needed. Another example is emerald, which is made up of a 6-faced (or 6-sided) prism with two hexagonal shaped terminations (a basal pinacoid). This means that two different kinds of faces are needed to enclose the space within the crystal. Hence, for a hexagonal shape, the prism and the pinacoid (two open forms) work together to enclose the space.

There a 48 different forms, some of which are illustrated below.

Figure 5.3.1*: Pedion (open)*

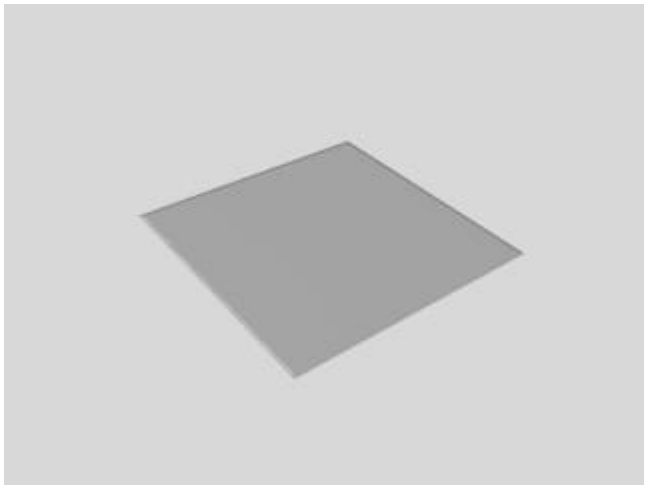


Figure 5.3.2*: Pinacoid (open)*

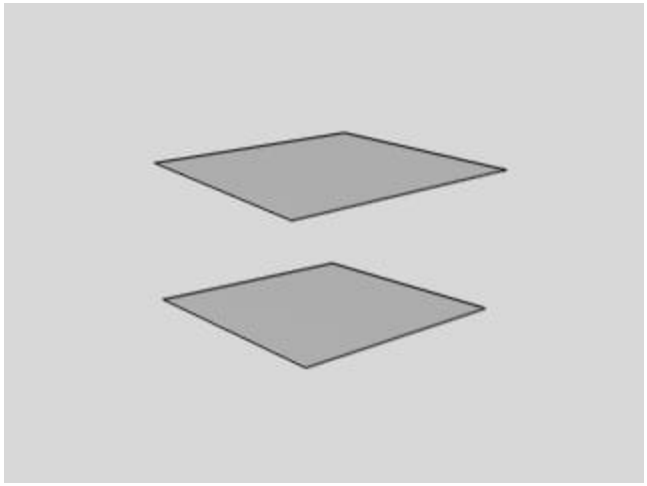


Figure 5.3.3*: Dome (open)*



Figure 5.3.4*: Tetragonal prism (open)*

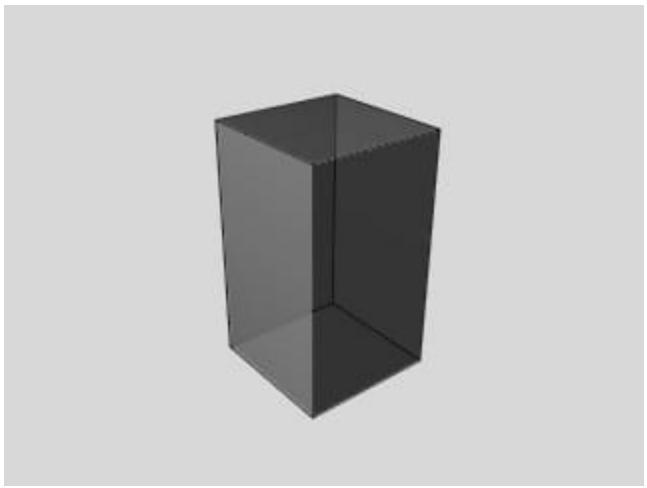


Figure 5.3.5*: Trigonal prism (open)*

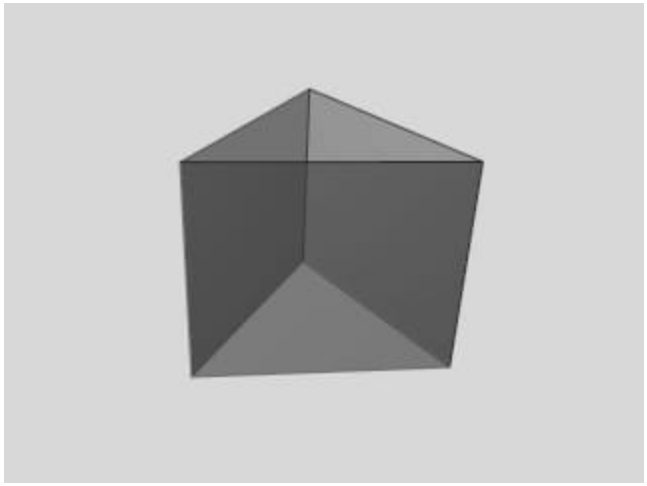


Figure 5.3.6*: Hexagonal prism (open)*

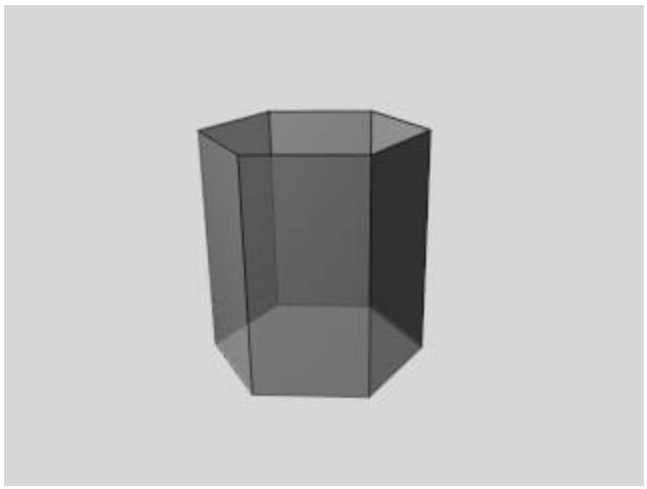


Figure 5.3.7*: Tetragonal pyramid (open)*

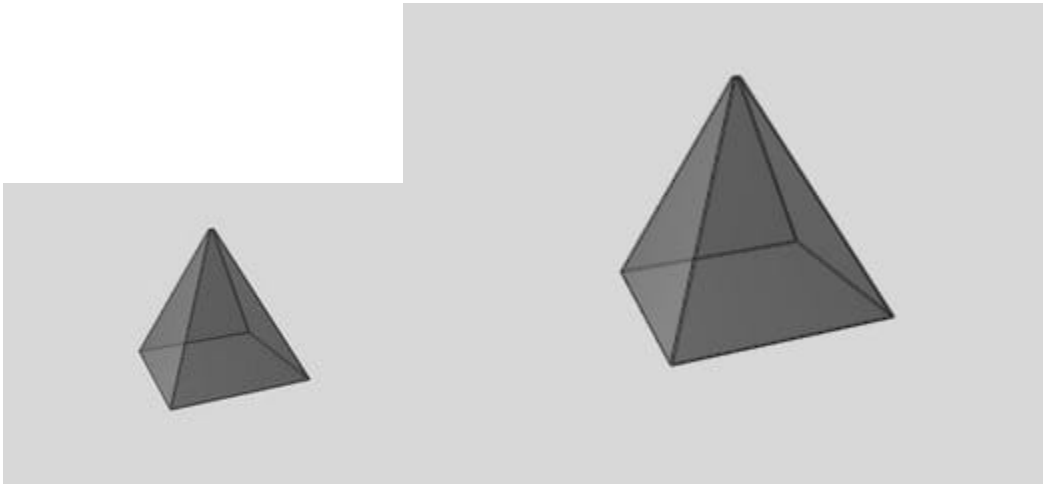


Figure 5.3.8*: Trigonal pyramid (open)*

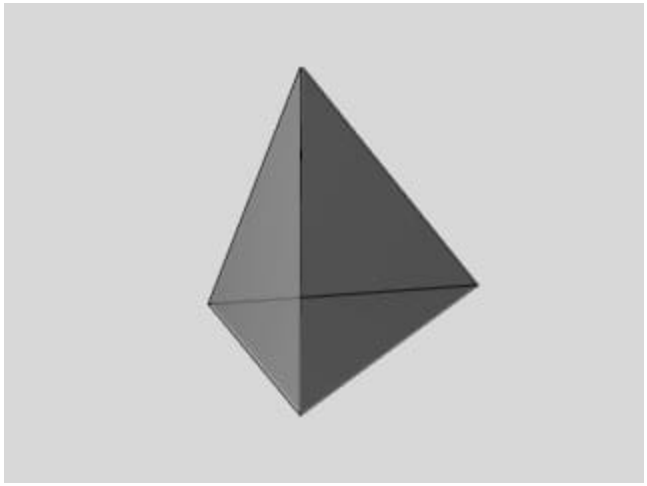


Figure 5.3.9*: Hexagonal pyramid (open)*

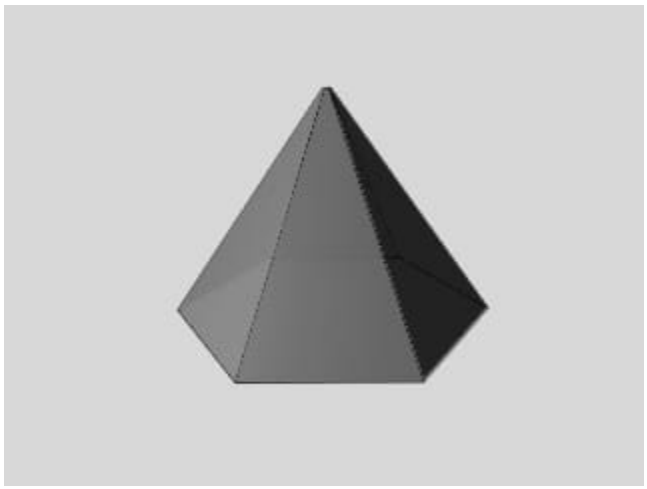


Figure 5.3.10*: Cube (closed)*

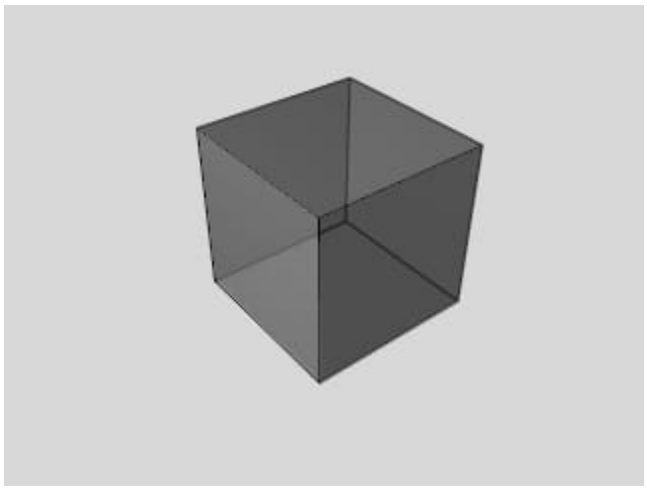


Figure 5.3.11*: Octahedron (closed)*

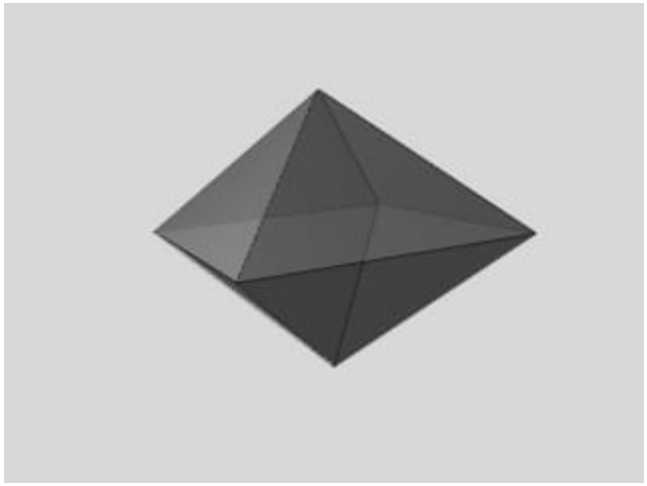
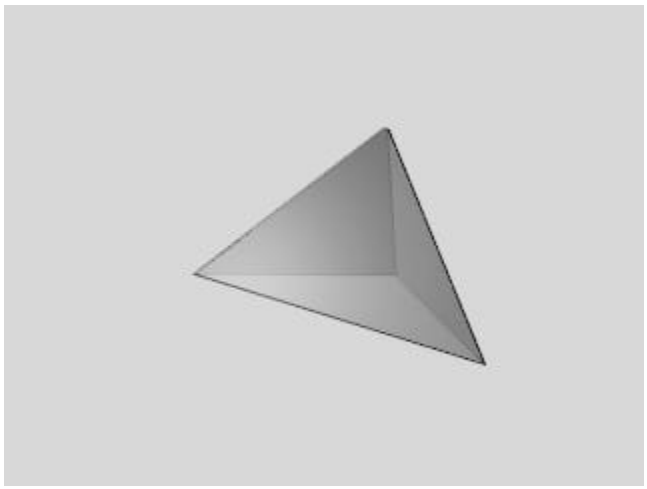


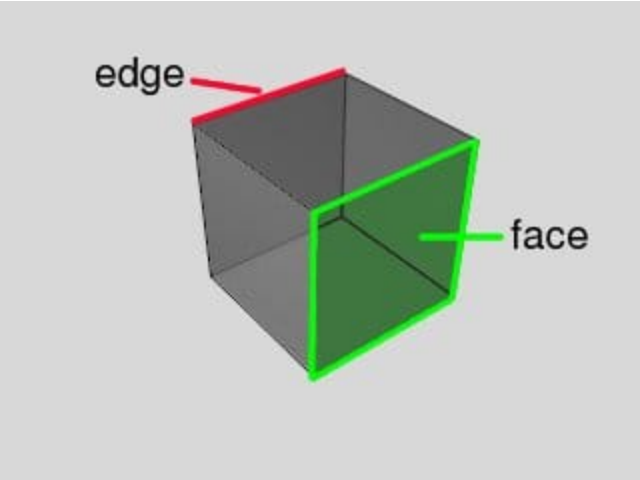
Figure 5.3.12*: Tetrahedron (closed)*



Forms terminology

You will find a lot of references to "faces" and "edges" while reading about forms and symmetry. A face is a flat surface on a crystal (sometimes named a "plane"). An edge is the division between two faces.

Figure 5.3.13*: faces and edges*



Sources

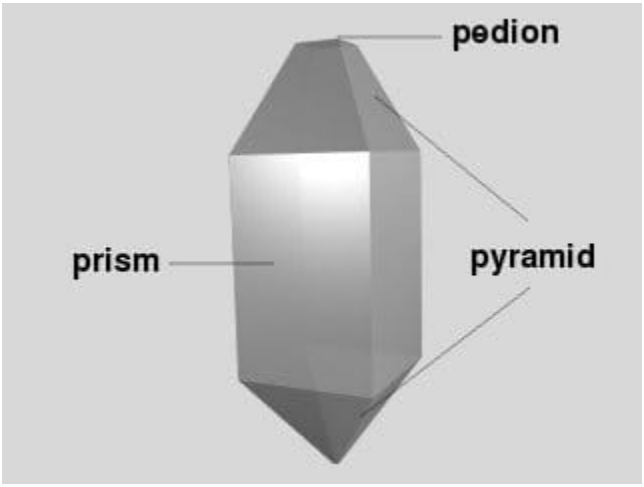
- Gemmology 3rd edition (2005) - Peter Read

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5.4: Habit

Basic

Figure 5.4.1*: Imaginary crystal, prismatic with pyramidal/pedial terminations*



The habit of the mineral is defined by the shape in which it will usually occur in nature. Contrary to form, these are not always ideal shapes, although some might be.

When we name habits, we change the suffix of the forms that make up the habit. For example, when the mineral has the form of an octahedron (as many diamonds have), we name the habit "octahedral".

When a mineral is made up of different forms, we name the habit accordingly. In the image on the right, the mineral exhibits 3 different forms (a prism, two pyramids, and a pedion). We name the habit "prismatic with pyramidal and pedial terminations".

There are many different types of habit that may have their own specific names:

- Acicular
- Bipyramidal
- Botroyidal (or globular)
- Columnar (or fibrous)
- Dentritic
- Dodecahedral
- Euhedral
- Mamillary
- Massive
- Octahedral
- Prismatic
- Scalenohedral
- Striations
- Tabular

Sources

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5.5: Symmetry

Basic

Axes of symmetry

Axes of symmetry have to do with a crystal's balance of shape when rotated around these imaginary axes.
Every crystal belongs to a particular crystal system (cubic, tetragonal, hexagonal, trigonal, orthorhombic, monoclinic or triclinic) and the symmetry for each of these systems is defined by ideal shapes.

Following is an illustration of symmetry axes in the orthorhombic system.
When determining the axes of symmetry, it is important to rotate (or spin) the crystal around that axis through a 360° rotation and judge how many times the exact image is repeated during the rotation.

Figure 5.5.1*: The basic form that makes up the orthorhombic system looks like a matchbox.*

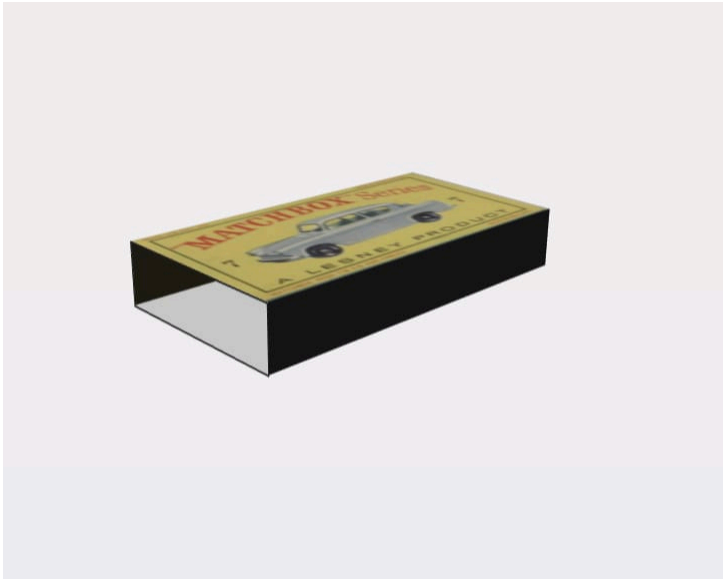


Figure 5.5.2*: Here the match box is represented as 3 pinacoids (3 parallel faces).*

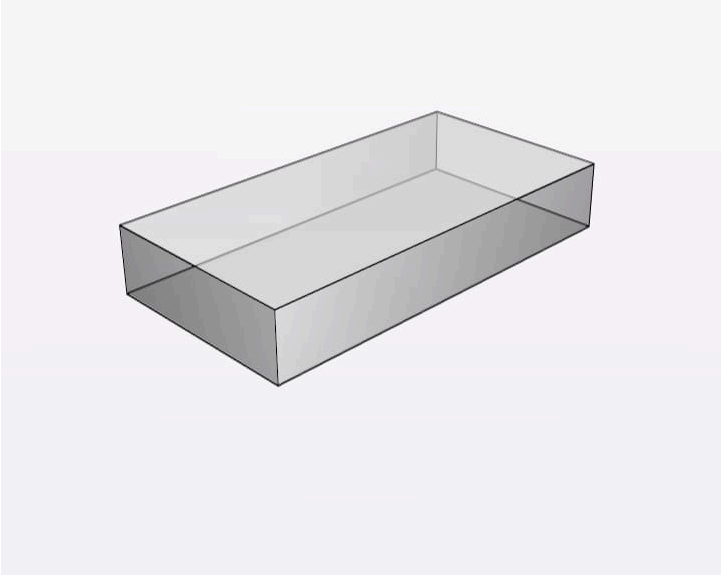


Figure 5.5.3: *An imaginary needle (axis) is pierced through the center of the top plane.*

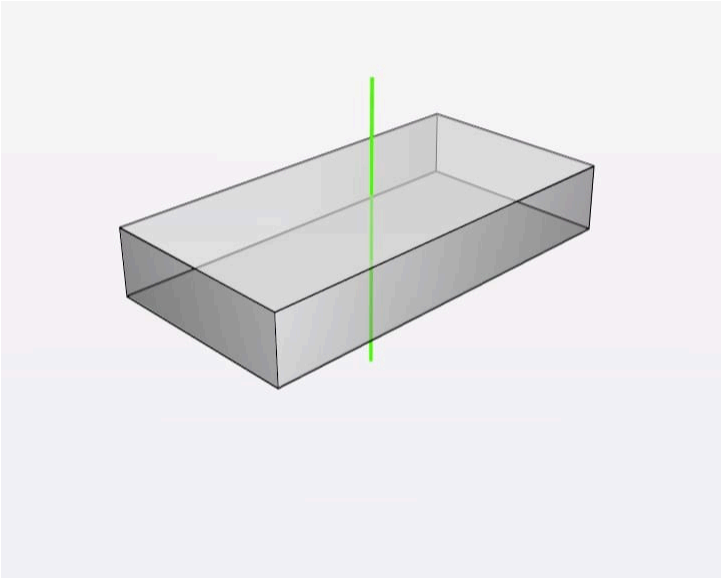


Figure 5.5.4: *We take an arbitrary plane as our starter for the rotation (the front plane in this case).*

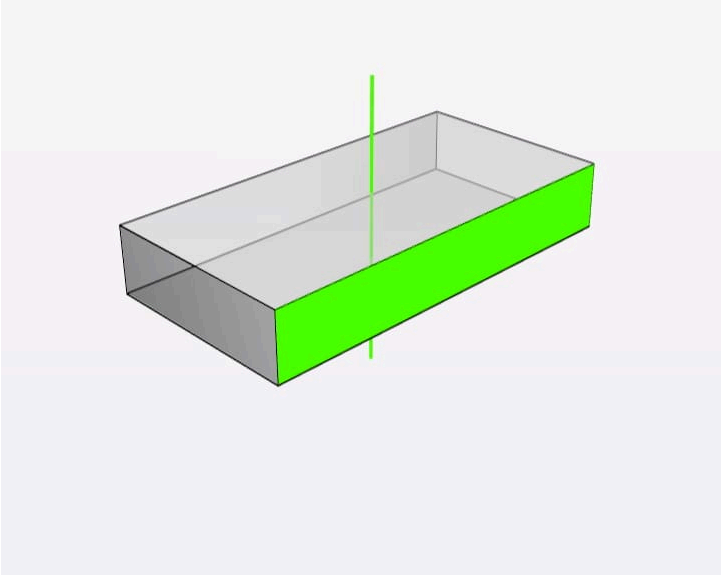


Figure 5.5.5*: During a 360° rotation of the box around the axis, the exact same image is shown twice.*

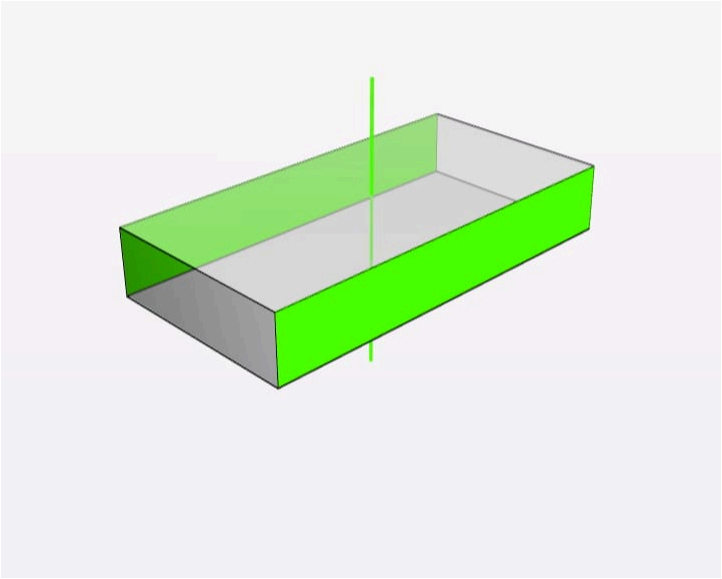


Figure 5.5.6*: The same process is repeated but now with the needle (axis) pierced through the side faces.*

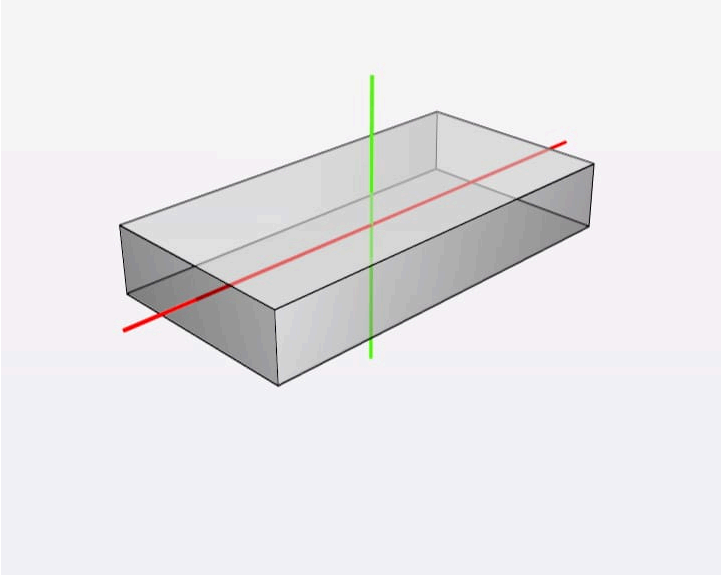


Figure 5.5.7*: We take another arbitrary plane as our starter for rotation (the top plane).*

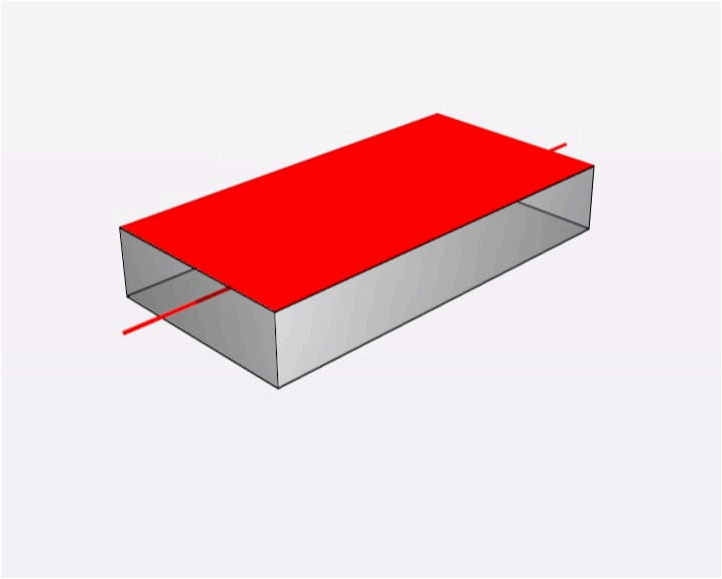


Figure 5.5.8*: Again during a 360° rotation of the box around the axis, the exact same image is shown twice.*

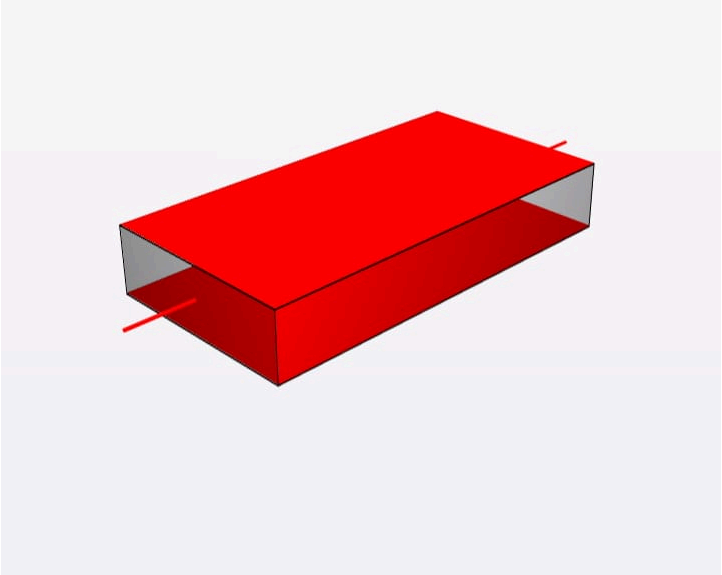


Figure 5.5.9*: The final axis of symmetry (in the orthorhombic box) is through the front plane.*

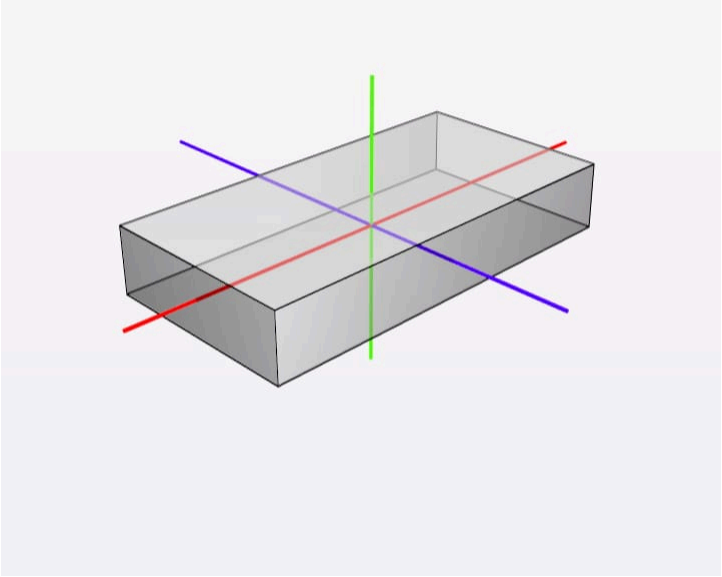


Figure 5.5.10*: We now take a pinacoidal face (the front plane) as the start of our rotation.*

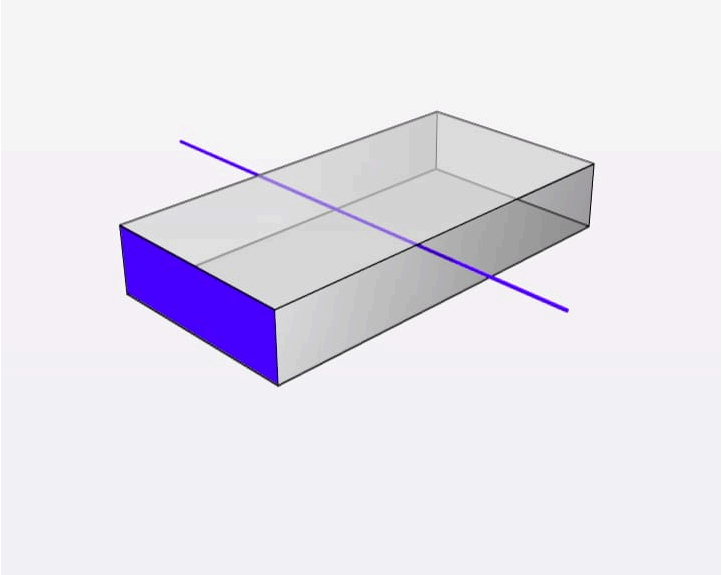


Figure 5.5.11*: And again, during a 360° rotation of the box around the axis, the exact same image is shown twice.*

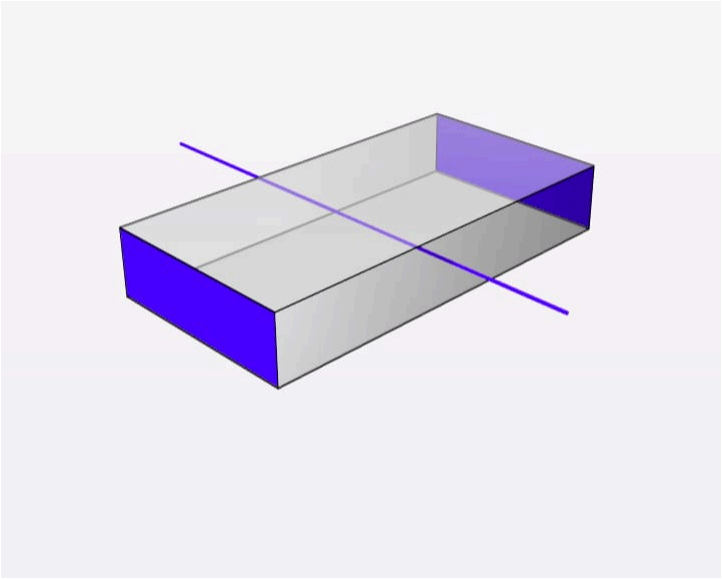
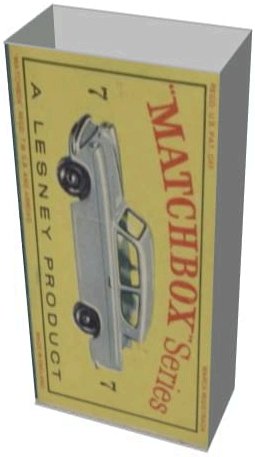


Figure 5.5.12*: If one would place the matchbox on a different pinacoidal face, one would get identical results.*



As can be seen in the above images, there are 3 axes of symmetry in the orthorhombic system and each axis produces the same image twice during a 360° spin around that axis.
When an axis shows the same image twice, we say it has a 2-fold axis of symmetry (or better: a "digonal axis of symmetry"). So the orthorhombic system is characterized by 3 2-fold axes of symmetry.

Other crystal systems will have fewer or more axes of symmetry. A 3-fold axis of symmetry means that the image is repeated 3 times (named a "trigonal axis of symmetry"), etc.

Planes of symmetry

Planes of symmetry can be regarded as mirror planes. They divide a crystal in two. Each side of the division is the mirror of the other while the total image is not altered by the mirror plane (the symmetry stays intact).
As with the axes of symmetry, the orthorhombic system is used for illustration and there are 3 planes of symmetry in this crystal system.

Figure 5.5.13*: First plane of symmetry*

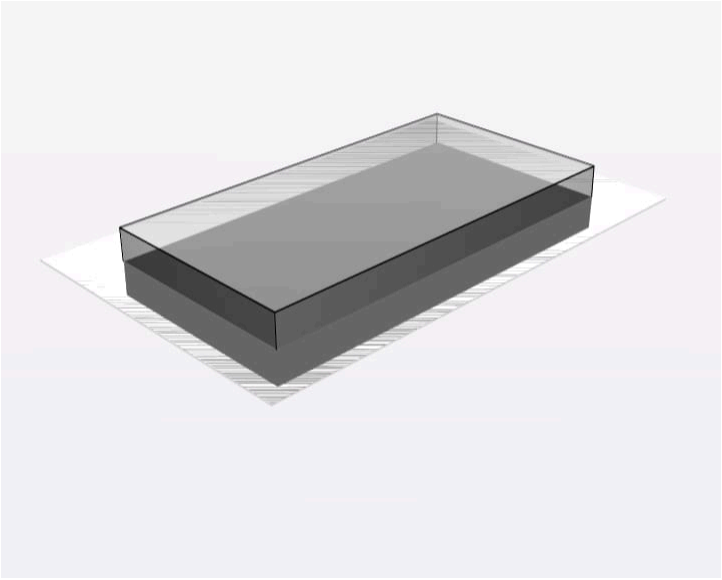


Figure 5.5.14*: Second plane of symmetry*

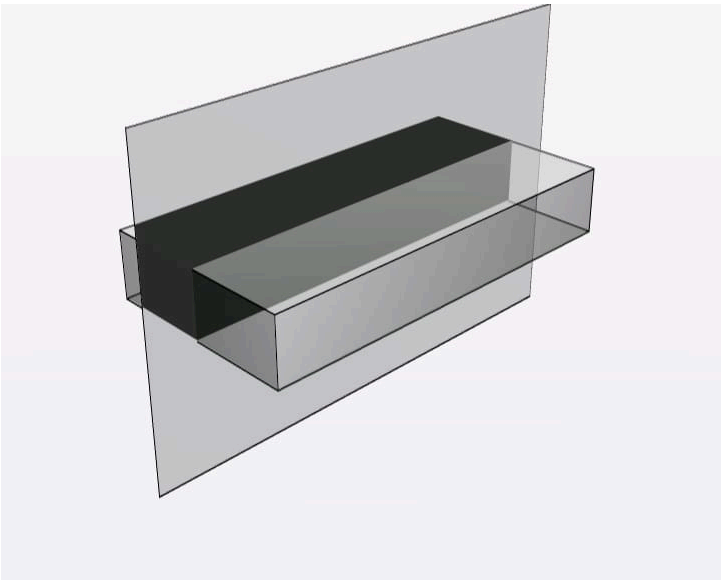
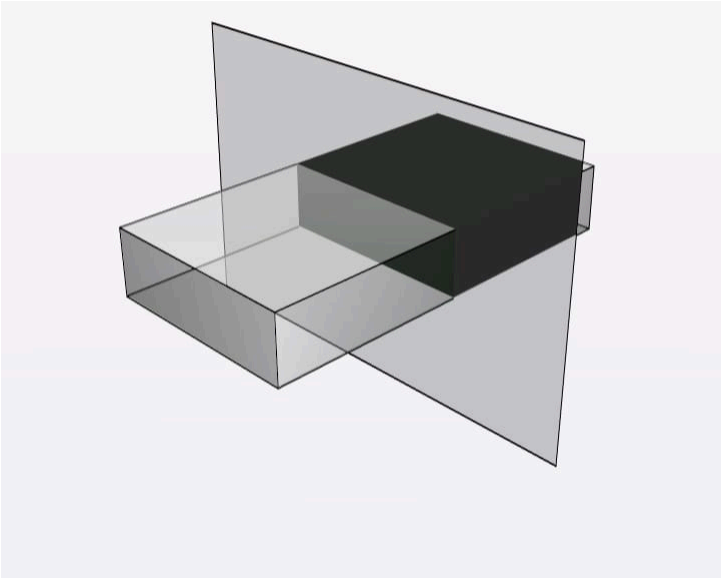
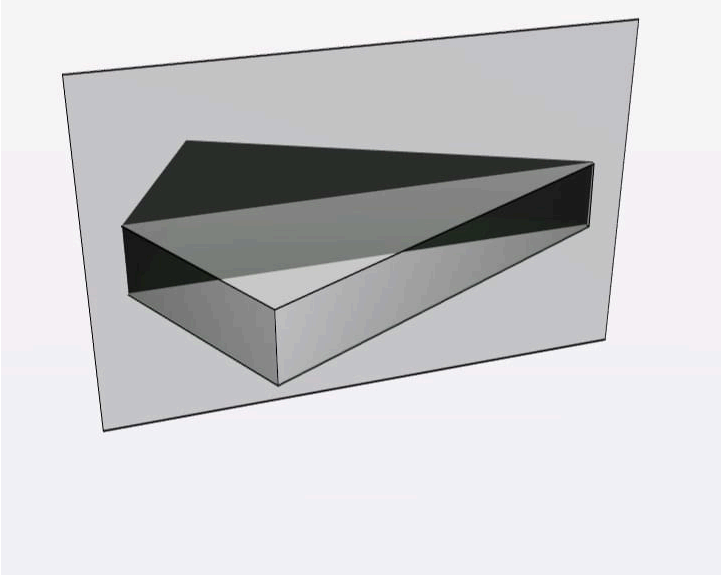


Figure 5.5.15*: Third plane of symmetry*



In all the above images, the dividing plane acts as a mirror plane. In other crystal systems, there may be fewer or more planes of symmetry.

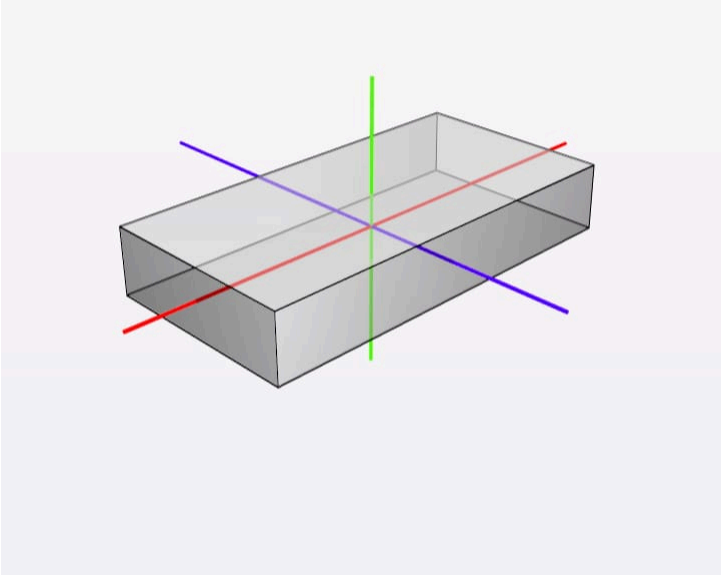
Figure 5.5.15*: Not a plane of symmetry*



To illustrate that not all divisions by a plane create a symmetry plane, the illustration on the above shows a mirror that transforms the crystal into a kite form instead of into its original prismatic shape.

Center of symmetry

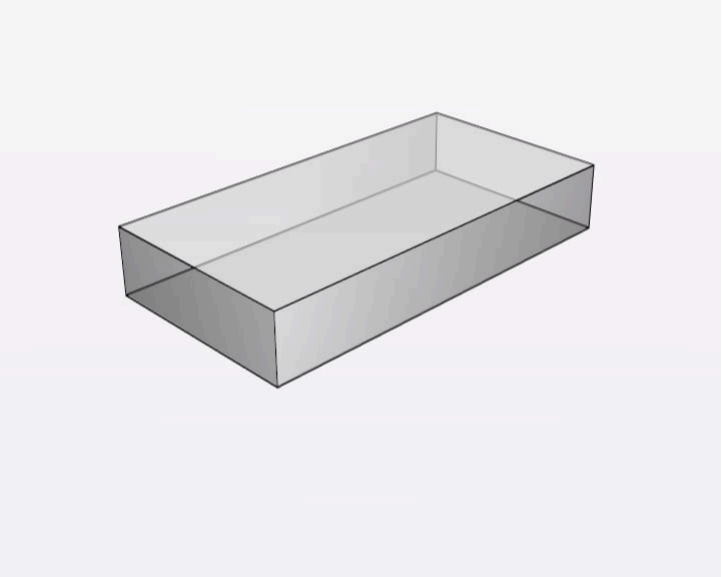
Figure 5.5.16*: Center of symmetry*



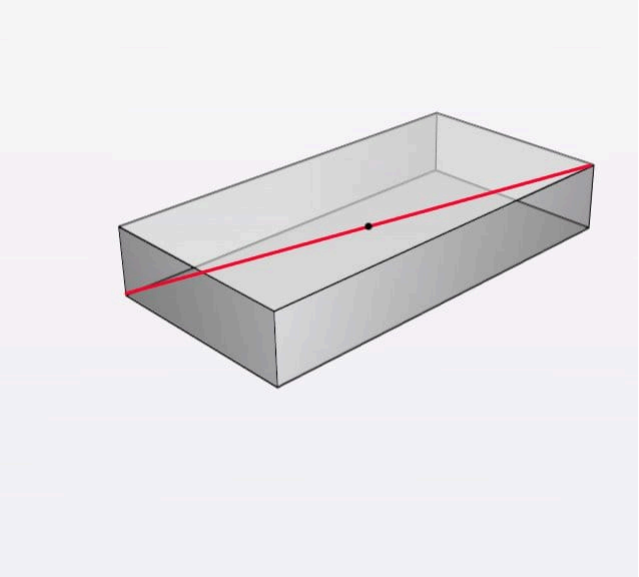
A center of symmetry is the central point from which crystal faces and edges appear the same on either end of the center.
In this image, the center of symmetry is where the green, the blue and the red axis of symmetry meet.

The center of symmetry is not always well understood. It is a central point inside the crystal through which faces and edges of one side of the crystal are connected to the other side of the crystal. This results in an "inversion" of the image. The "center of symmetry" is also named an "inversion center".

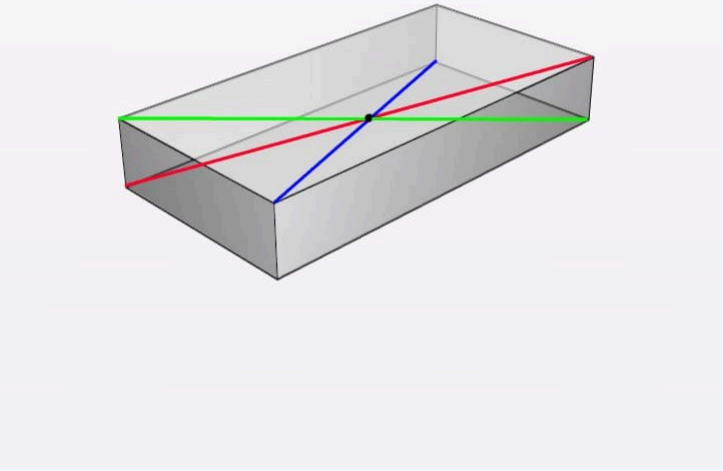
If you take a single point of a face and draw a line from that point through the center of symmetry, that point will be connected at the other side (but upside down and rotated - inverted). Both distances from the center should be equal.



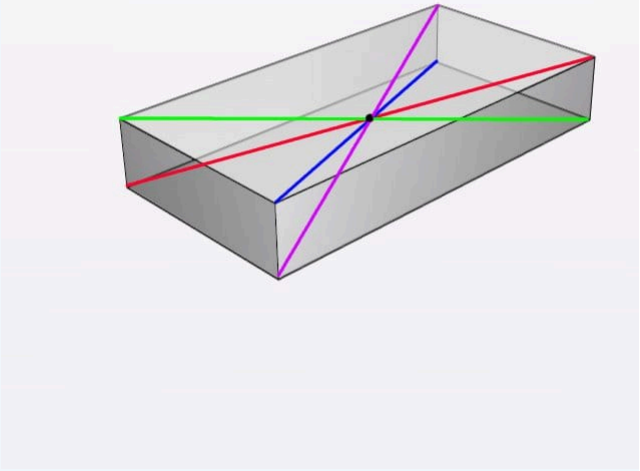
Start out with a matchbox and we draw lines from each corner of the rear plane through the center



The first corner of the rear plane (lower left) will be conne through the center at the front plane



The upper left corner of the rear face will be connected to the lower right corner of the front plane



And the upper right corner of the rear plane will become th left corner of the front

All the 7 crystal systems will have a center of symmetry for a particular form, yet some forms may not show them. For example, in the trigonal system, the trigonal prism will not have a center of symmetry but the rhombohedron will.

Sources

- Gemmology 3rd edition (2005) - Peter Read

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5.6: Twinning

Basic

Minerals do not always grow under ideal conditions to form perfect crystals. During growth (or after), some crystals may form twins.

There are basically two types of twins:

- contact twins
- penetration twins

There are typically 3 causes of twinning:

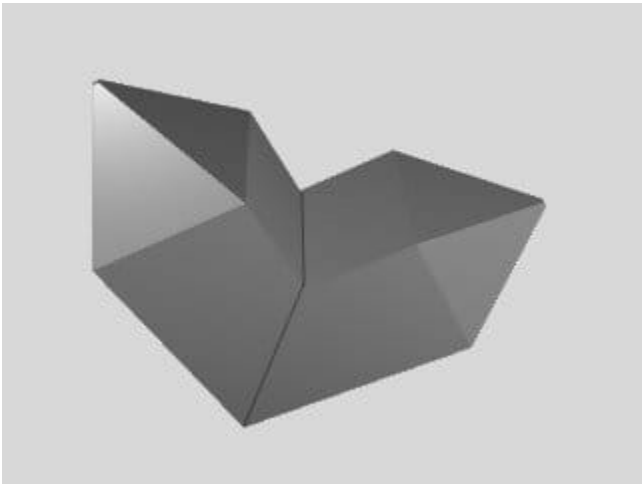
- during crystal growth
- from transformation
- by deformation

Types of twins

Contact twins

Contact twins share a single plane (or face).

Figure 5.6.1*: Geneculate (knee-type) twinning in zircon*



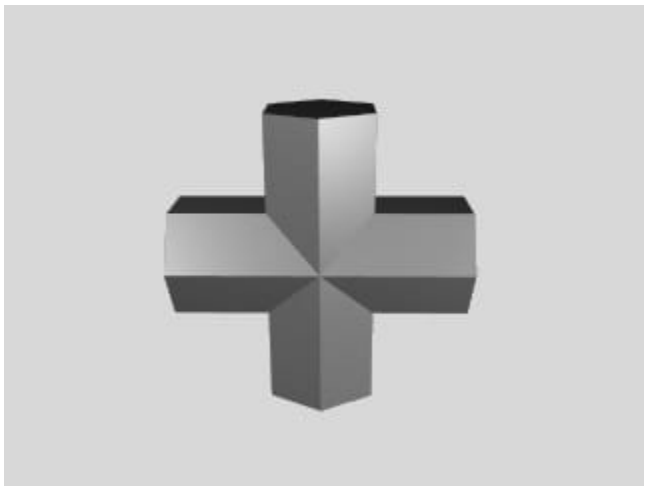
Penetration twins

Penetration twins share a single axes (usually a rotation axis).

Figure 5.6.2*: Fluorite penetration twin (two cubes intergrown)*



Figure 5.6.3: *Staurolite penetration twin (two hexagonal prisms intergrown)*



Causes of twinning

During growth

During the growth of a crystal, there may be changes inside the magma (like temperature, pressure, and flow) which cause elements of the magma to alter a crystal's orientation.
Most twinning occurs under these circumstances.

Transformation

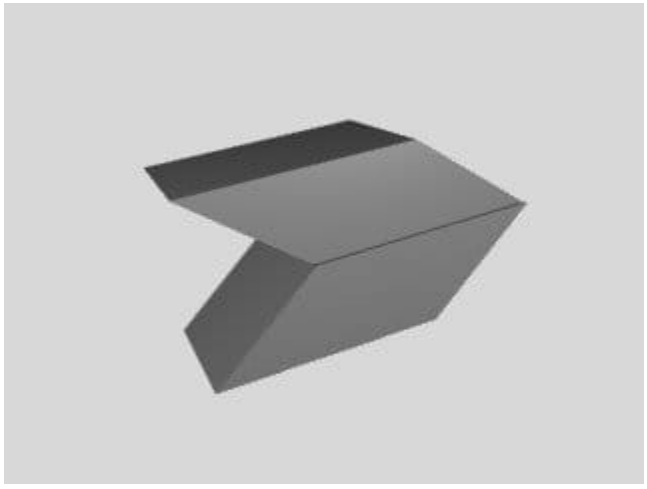
When a fully grown crystal experiences sudden change in temperature and pressure, the internal arrangement of atoms can shift. A good example of this is quartz.
At temperatures above 573°C, quartz is hexagonal and is termed beta-quartz. Below that temperature, beta-quartz will transform into trigonal alpha-quartz, and twinning will occur during this transformation.

Deformation

When a fully grown crystal undergoes mechanical stress (such as pressure), the crystal lattice may be distorted. One can imagine this by laying the shell of a matchbox on a table and applying slight pressure to it. The matchbox will shear, distorting its form. When two matchbox shells are placed next to each other, the same pressure will cause them to shear into an arrow head.

An example of this is calcite.

Figure 5.6.4*: Deformation twin (contact)*



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5.6.1: External Links

- The 48 Crystal Forms
- Crystallography (3-D java applets)

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6: CLEAVAGE

6.1: Cleavage
6.2: Parting
6.3: Fracture
6.4: External Links

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6.1: Cleavage

Cleavage is the splitting of a gemstone along the direction of its crystal faces where atoms have weaker bonding. This can occur only in crystalline minerals when a precise blow is given in a particular direction. The result of cleavage is a more or less flat plane with often a silky luster.
Cleavage is a reproducible property of a gemstone and can be done at any point of the cleavage direction.

There are several directions of cleavage.

- Prismatic cleavage
- Basal cleavage
- Pinacoidal cleavage
- Octahedral cleavage
- Rhombohedral cleavage

The quality of cleavage is expressed with a few simple phrases.

- Perfect
- Good (or imperfect)
- Fair (or moderate)
- Poor (or weak)
- None

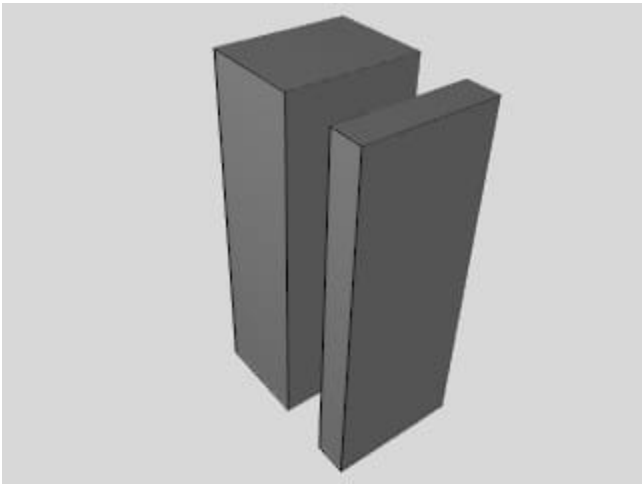


Figure 6.1.1*: Prismatic cleavage*

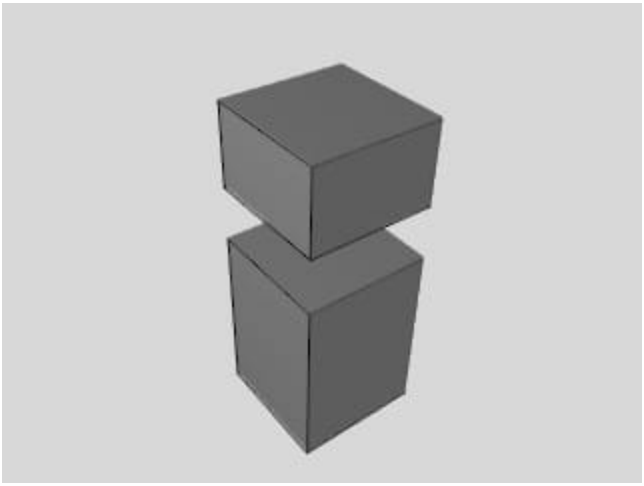


Figure 6.1.2*: Basal cleavage*

Stones and their cleavage directions:

Table 6.1.1

Cleavage	Directions	
Basal	1	
Prismatic	2	
Cubic	3	
Rhombohedral	3	
Octhahedral	4	
Dodecahedral	6	

Sources

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6.2: Parting

Parting is the splitting of a gemstone along twinning or pressure planes.
Although this is similar to cleavage, parting can only be done along certain, well defined, planes of weakness and it is not reproducible like cleavage. Usually, these parting planes are created during growth of a crystal when pressure was applied to the crystal causing it to (partially) break or fracture. Later overgrowth then heals the fracture, leaving a weak area inside.

One of the most profound examples of parting is mica which consists of many very thin layers that can be easily parted with the fingernail. It is this mineral that is traditionally used for quarter wave plates.

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6.3: Fracture

Fracture is the random breakage of a gemstone when being hit with a sharp or hard object along a direction other than then the direction of cleavage or parting. The most common type of fracture is termed "conchoidal" (shell-like).

The types of fracture are:

- conchoidal
- uneven
- even
- splintery
- granular

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6.4: External Links

- Parting
- Cleavage

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7: OPTICAL PROPERTIES OF GEMSTONES

7.1: Optical Properties of Gemstones
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7.3: Reflection
7.4: Adding Arrows
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7.1: Optical Properties of Gemstones

The way in which the behavior of light is affected by gemstones is important because this leads to:

- Practical considerations about the way and shapes in which gemstones are cut, in order to display their beauty to the best advantage.
- The observation and measurement of that behavior as a means of identification of gemstones.

In diagram:

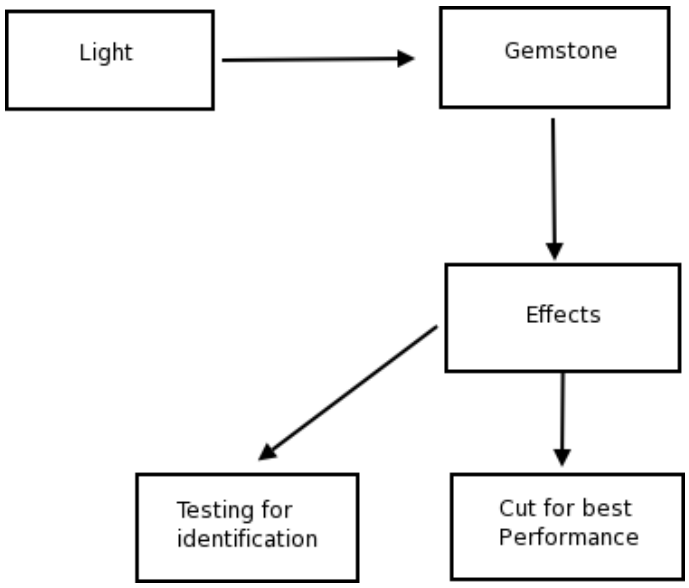


Figure 7.1.1

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7.2: Nature of Light

The beauty of a gemstone depends almost entirely upon the way it interacts with the light. The fire of a Diamond and the play of colors in an Opal are just two examples.

Scientists recognize two different theories to explain the way in which light is transmitted:

- The electromagnetic wave theory
- The quantum theory

Both theories are important to learn so you may understand the causes of color in gemstones.

The wave theory

Basic

This theory, developed by Dutch scientist Christian Huygens (1629-1695) and later explored by others, states that light is a form of energy traveling in a wave motion.

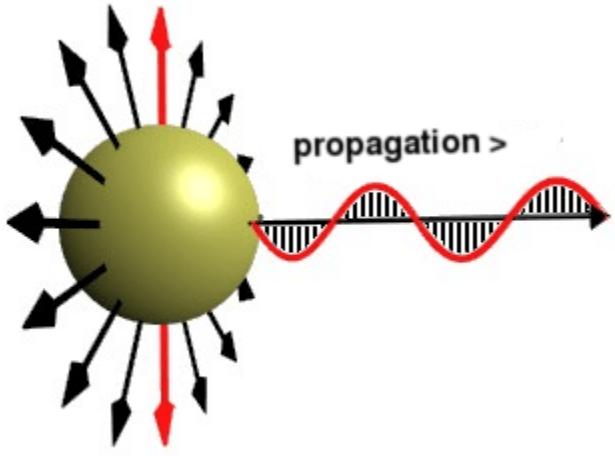


Figure 7.2.1*: Transversal light*

The wave motions of light travel from its source in all directions. It can be compared to what happens when you throw a brick in a puddle of water: the water's surface starts to vibrate and these vibrations cause transversal waves. Transversal waves vibrate in the direction (like up and down) perpendicular to the direction in which the wave propagates.

Note: although we can't see light we can see color. This is caused by absorption.

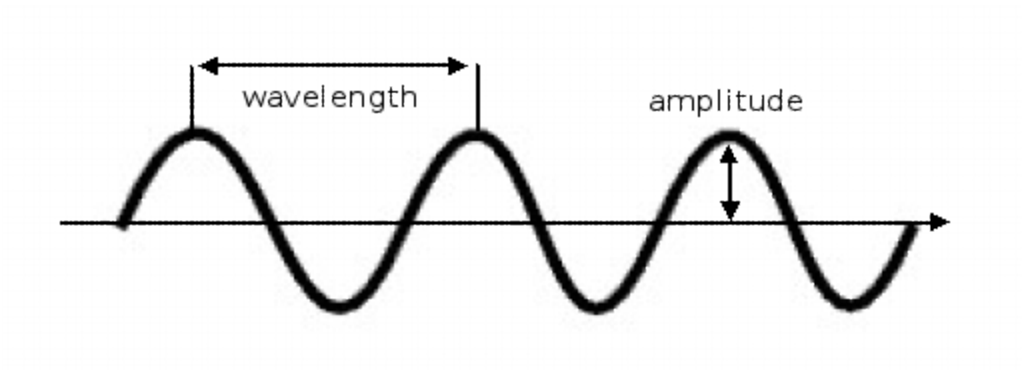


Figure 7.2.2: *Wavelength and amplitude*

There is a relationship between wavelength and color of light, which is explained by what we call the electromagnetic spectrum. Red light travels at a wavelength between 740 and 625nm, blue light between approx. 420 and 380nm.

Wavelength is measured in nanometers (nm), which is one-billionth of a meter. (An older measurement unit is Ångström, which equals 10nm, but this unit is no longer used.)

The amplitude of a wave defines the intensity of the color. The higher the amplitude, the more intense the color. If there is almost no amplitude in the wave, then the color will be almost to entirely black.

The quantum theory

Basic

This theory was developed by Max Planck and Albert Einstein. It states that light energy can be absorbed and emitted only in small and discrete amounts, called "quanta" (later known as "photons"). This theory is used to explain certain causes of color in gemstones and the phenomenon of fluorescence.

Fluorescence is the emission of visible light by a substance, such as a gemstone, when irradiated by energy of a wavelength shorter than the emitted wavelength. Some rubies can be made to glow like red-hot coals when they are bombarded by ultraviolet radiation.

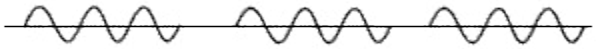


Figure 7.2.3: *Photons (light energy) traveling in small packages ("quanta")*

This theory is very important when explaining the causes of color in gemstones, which is primarily due to absorption of energy (from the photons) and the emitting of that energy.

The image shows that a photon seems to have a constant amplitude and frequency, yet in reality this is not the case. From a gemological point of view, we assume it does.

Although Einstein never did like the quantum theory, he was the founder of it with his famous equation:

$$E = hf \tag{7.2.1}$$

Where E = energy, h = Planck's constant and f= frequency.

It was mainly for this (which solved the photoelectric effect) that he was awarded the Nobel Prize in physics (1921), not for his Relativity Theory.

The electromagnetic spectrum

Basic

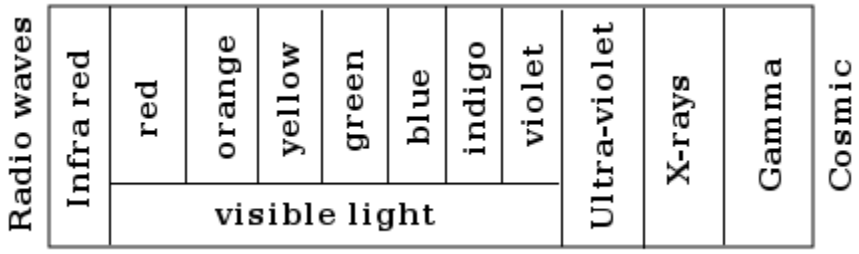


Figure 7.2.4***:*** *The electromagnetic spectrum*

The electromagnetic spectrum consists of the entire range of wavelengths, from the longest radio waves through continually shortening wavelengths to infrared, visible light, ultraviolet, and X-rays. And finally the shortest waves of all, cosmic rays.

The seven colors of the visible light spectrum are red, orange, yellow, green, blue, indigo and violet. When all these colors are mixed, we see what we call "white light". When there is no color at all, we see black.

Infrared is used in reflectivity meters, as an identification aid. Visible light reveals the color and beauty of gemstones. Ultraviolet may produce fluorescence effects. X-rays may also produce fluorescence and may be used for color alteration and to enable us to distinguish between various types of pearls. Gamma rays may be used to alter the color of certain gemstones.

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7.3: Reflection

Basic

Reflection is the return by a surface of some of the light which falls on that surface. (Other parts get absorbed or refracted).

There are two main laws (called "the laws of reflection") that play a role in this:

1. The angle of reflection of a ray (**r**) of light is equal to the angle of the ray of incidence (**i**).
2. The incident ray (**I**), the reflected ray (**R**) and the normal (**NO**) all lie in the same plane. In this case, it is the plane of your computer monitor.

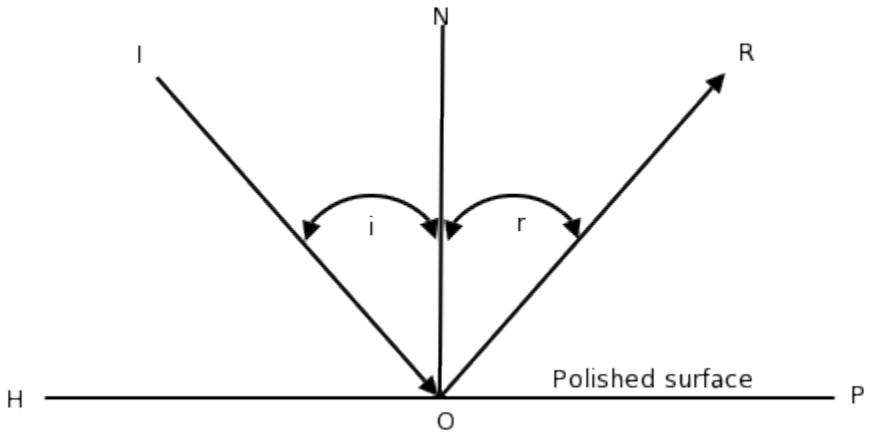


Figure 7.3.1*: Law of Reflection*

The angle of incidence (**ION**) and the angle of reflection (**NOR**) are both measured by reference to an imaginary line called the normal (**NO**), which is perpendicular to the reflecting surface (**HP**), at the point of incidence (**O**). The point of incidence is the point at which the incident ray strikes the reflecting surface.

Understanding these basic principles are important in order to understand the many gemological terms that are used to describe optical effects caused by reflection.

Amongst those effects are:

- Luster
- Sheen
- Brilliance
- Interference

Advanced

Fresnel reflection

For light that is incident close to the normal (to about 10°), the amount of reflection can be calculated by the Fresnel equation for reflectivity.

$$Amount\ of\ reflection = \frac{(n_2 - n_1)^2}{(n_2 + n_1)^2} \tag{7.3.1}$$

For light traveling from air to diamond that translates to:

$$\frac{(2.417-1)^2}{(2.417+1)^2} \approx 0.17 = 17 \tag{7.3.2}$$

Brewster Angle

In 1812, Sir David Brewster (1781-1868) described a new phenomenon of light. He found that, when light falls on an optically denser object (like water) at a certain angle, the reflected component of the unpolarized light will be completely polarized in the plane of the surface off which it reflects. In the case of water, it would be the horizontal plane.

He also observed that the angle of the refracted ray was at 90° to the reflected ray (at this specific angle).

This angle is named *The Brewster Angle*. It varies for every two materials that are in contact, relating to the refractive indices of the materials.

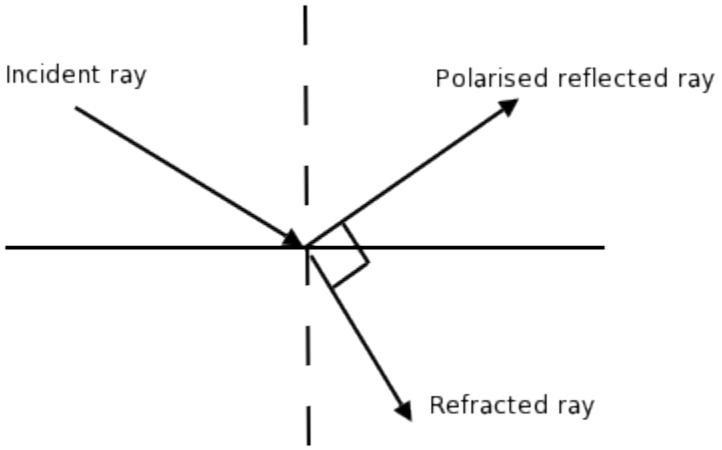


Figure 7.3.2*: Brewster Angle*

When the refractive indices of both materials are known, one can calculate the Brewster angle.

$$\arctan \theta_B = \frac{n_2}{n_1} \tag{7.3.3}$$

(where Θ_B is the angle between the incident ray and the normal).
The latter makes it possible to use reflection as an aid to determine the refractive index of polished stones.

As the reflected ray is completely polarized in the horizontal plane at that specific angle, one could insert a vertically oriented polarizing filter to block all the reflected light (similar to how sunglasses work). By measuring the angle of the incident light, at which point no light passes through the polarizing filter, one may calculate the refractive index.

If one were to use monochromatic light that is polarized in the vertical plane, there would be no need for a horizontal orientated polarization filter as at the Brewster Angle that light will not be reflected. This is the principle of "The Brewster Angle Meter" developed by Peter Read.

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7.4: Adding Arrows

This essay is largely based on Richard Feynman's book "QED - The Strange Behavior of Light and Matter" and his lectures in Auckland, New Zealand. The first being the written version of the many lectures held by Feynman at universities around the world in the 1970' and 1980's.

Quantum electrodynamics is a topic not very well understood by gemologists (or even by physic majors), but with the simple concept of "adding arrows" the strange behavior of light can, at least partially, be explained. Nobel Prize winner Richard Feynman had the ability to teach hardcore quantum theory at a novice level maybe only to be surpassed by Walter Lewin. Throughout everything Feynman freely admits that some things just can not be explained at present, nor that anything he lectured is correct. In 10 years we might have much more insight in the strange behavior of light, but at present we will have to do with empirical knowledge and our limited understanding.

The main objective of this essay is therefore not to be authoritative or correct, just to dive a little deeper in the topic of light so we may understand how light works. From why light doesn't travel in a straight line to how diffraction works, it can all be explained by the simple concept of "adding arrows".

Reflection

When a light source is pointed at a reflecting surface, we are taught that the reflection will reach a point on the opposite of the normal and that the angles of incidence and the angle of reflection are equal. The incident ray, the reflected ray and the normal all lie in the same plane. That is the "law of reflection". A logical interpretation of that might be that light will always follow that path of least distance (or even least time). That raises a few questions, as how much of the light will be reflected from the glass plate. Or if we would paint a portion of the glass black, would it still be able to reflect light from light source A to detector point B? According to the usual law of reflection, the latter should not occur. In reality, it could reflect more.

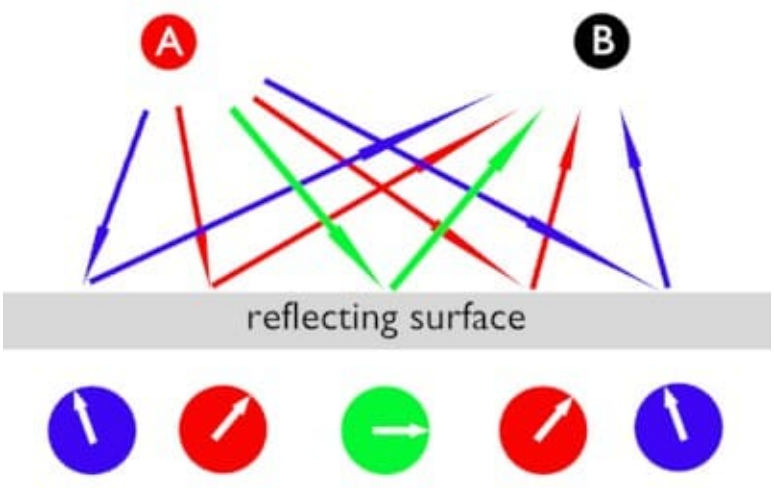


Figure 7.4.1***:*** *Possible paths light can take when traveling from point A to point B via a reflecting surface*

For us to understand this, we need to let go of the idea that light travels only in a straight line from A to B or that there is only one path a light ray can take to get from A to B, via a reflecting surface, when the shortest path between A and B is blocked.

When a photon travels from point A to point B via a reflecting surface, it can take an infinite amount of paths to reach B. The shortest possible route being dictated by the law of reflection (depicted as the green arrows). However there is no reason why the photon could not take a longer path, and in fact, it does. It could easily follow the red paths (which are longer paths) or the blue paths (even longer) or anything in between. If we were to place a detector at point B and measure the time it takes to get from

point A to B via the reflecting glass, the time for every photon to arrive at point B will be different. A good indicator that light does not always travel the shortest distance.

If we were to take a stopwatch with counter-clockwise rotating hand, the hand would stop at a different "hour" for each of these paths and we can think of the direction the hand is pointing to as an "arrow" (as indicated at the bottom of the image).
The lengths of the arrows are arbitrary and the same for every stopwatch.
The arrows are known by physicists as "phasors" and the direction in which they point is referred to as the "phase angle".

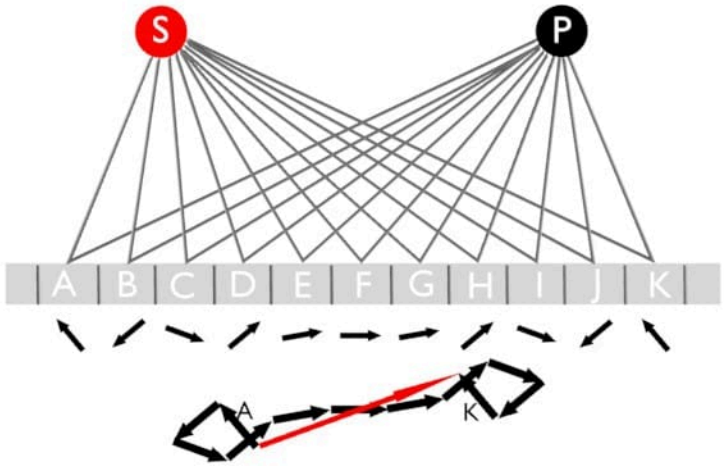


Figure 7.4.2***:*** *Close up of reflection on different spots of a mirror with arrows and the adding of arrows*

We could divide the reflecting surface into small portions (an infinite amount) and calculate the time it takes for a photon to get from source **S** to a detector **P** (P for photomultiplier). The stopwatch (with a very fast rotating hand) is started when the photon is emitted at **S** and stopped when it is detected at **P**.
Although the mirror can be divided into an infinite amount of small sections, for simplicity only 11 are drawn (from A through K). The small arrows below the sections represent the directions that the stopwatch hand is pointing at when the experiment is done.

We then start "adding the arrows", starting with arrow A. We do that by placing arrow B with its tail on the head of arrow A (**without changing the direction of the arrow**). Arrow C will be placed with its tail on the head of arrow B and so forth until we get a snake-like figure of arrows.
We then draw a final arrow that starts at the tail of A and ends at the head of arrow K (seen as the red arrow). This final arrow is the amplitude of all the photons that are reflected from the mirror.
As can be seen in the image, the sections E, F and G contribute the most to the final arrow. While the reflection in the outer regions of the mirror tend to detract from the final arrow. This means that the amount of reflection of a mirror is largely due to reflections around the centerpoint (**F**), and not of the centerpoint alone as we learned in the classical view of reflection.

As can be seen from the arrows, the sections A and B are causing the final arrow to be shorter and in fact interfere with the final amount of reflection. One could ask oneself, what would happen when we could get rid of one of those interfering arrows. One way of doing that is by making that section not reflect, for instance by painting it with a non-reflecting paint.

Diffraction

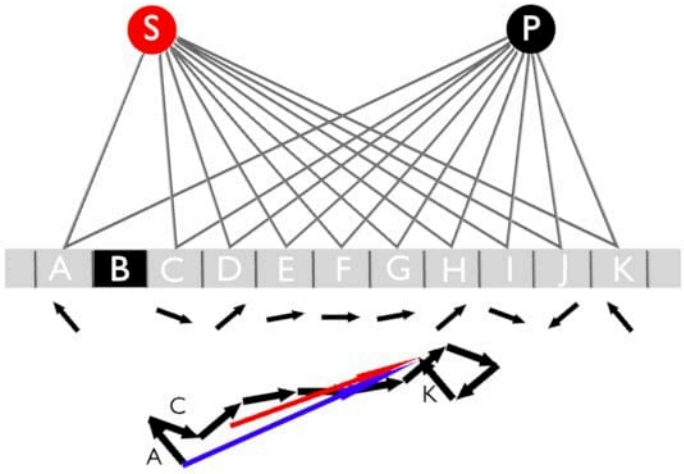


Figure 7.4.3***:*** *Removing a reflection section can add to the total reflection*

When we take away the reflection of a particular section, we also take away the arrow (as there is no reason to time the reflection on a non-reflecting surface). This means that the adding of the arrows will now change. As we removed the arrow that belonged to section B, we now must place the arrow from C on the arrow of A.
This results in a longer final arrow (from A to K) as seen in the image as a blue arrow (the original red arrow is left in to show the difference). This means that by removing a specific section of the mirror (by making that part non-reflecting), the total reflection of the mirror can be increased. Strange but true.

As always, there is no such thing as a free lunch and there is a catch. The removed section needs to be very small, a strip of about 1/1000th of a millimeter, and a sequence of those small strips will only reflect monochromatic light.
An added, and not anticipated, bonus is that if you move the detector, it will reflect another color of the visible spectrum. Thus that part of the mirror is now working as a diffraction grating.

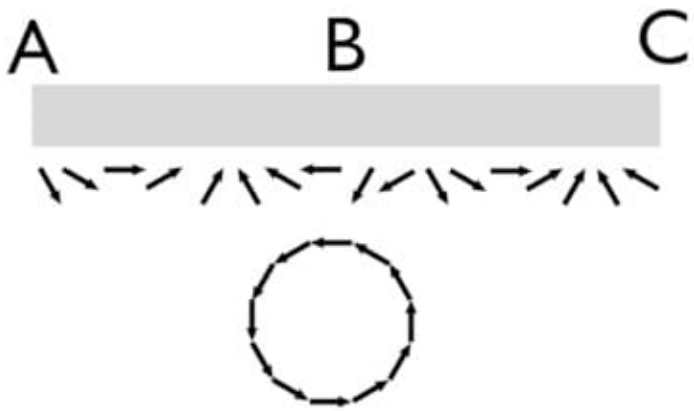


Figure 7.4.4***:*** *Interference of arrows after adding*

A close up of section A, B and C (the outer perimeters of the mirror) shows that many photos of light hit a specific area. One can draw in as many as one likes. All of them will need a different time to get to the detector and thus all will have a specific arrow associated with them. The area A to C shows arrows that interfere with each other, in effect canceling each other out and that region will therefore not contribute to the final amount of reflection of the whole mirror. When the arrows of that region are added (heads to tails) they form a circle or a spiral of arrows.

When one would make the areas that are detracting from the total reflection, i.e. the arrows who are pointing in the "wrong" way, non-reflecting then the overall reflectivity of the mirror will increase.

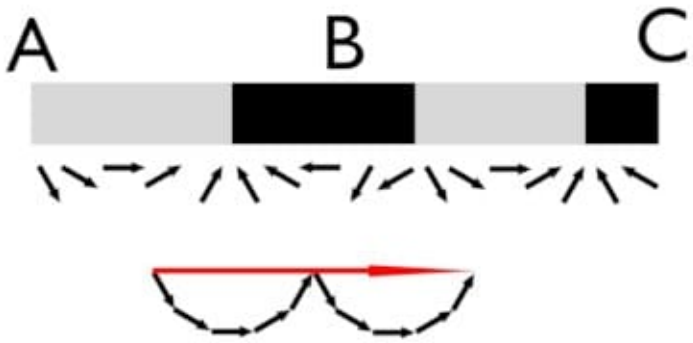


Figure 7.4.5***:*** *Increased reflectivity after adding of the arrows, diffraction*

One could make the areas where the arrows are pointing the wrong way black to make it non-reflective or one could etch away areas where the arrows are pointing in the desired direction. When one does either of the two, a diffraction grating is created.

Of course, the spaces between the reflecting and non-reflecting parts (named "grooves" in a diffraction grating material) are very closely spaced.

As mentioned earlier, the reflection on the grooves only works for monochromatic light, like red light, because the stopwatch for blue light spins faster than for red light (so the arrows would point in a different direction for blue light). However if one would move the detector, it works again for blue light (but not for red light).
If our eye is the detector, then it could work for both blue and red light (and everything in between) because our eye has a wide view and acts like many detectors at different places.

References

- *QED - The Strange Behavior of Light and Matter* (2006) - Richard Feynman ISBN 0691125759
- Richard Feynman - The Douglas Robb Memorial Lectures on video

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7.5: Luster

Luster (or lustre) is a surface gloss (caused by reflection), which depends to a large degree on:

- the refractive index.
- the ability to take polish of a gemstone.

The better the polish of the gemstone, the better the luster.

Since hardness defines what polish a stone can take, you can state:

- The amount and quality of the reflected light (which is called luster) is the highest for gemstones with a high refractive index, which also take an extremely good polish. In practice, these are usually the stones with the greatest hardness.

However, there is no direct relationship between hardness and luster. For instance: Sphalerite, while having an RI of 2.39, only has a hardness of 3.5 on Moh's scale, yet has a sub-adamantine (not quite diamond-like) luster.

The following terms are used to describe the luster of various gemstones:

1. Adamantine: the type of luster described by Diamond.
2. Sub-adamantine: gemstones having a high RI (but lower than Diamond), like Zircon and Sphene.
3. Vitreous: gemstones whose refractive indices fall within the range of middle values such as Emerald, Ruby, Spinel and most other transparent gemstones. Vitreous luster is sometimes described as "glass-like".
4. Resinous: gem materials that are soft and have low refractive indices, like Amber and Opal.
5. Waxy: an almost matt surface like that exhibited by Turquoise and Jadeite.
6. Silky: certain fibrous materials such as Gypsum and Malachite.
7. Pearly: the luster seen in Pearl, Moonstone, and Talc.
8. Metallic: the very high luster shown by metals such as gold and silver, and by minerals such as polished Hematite.

According to Robert Webster in "Gems: Their sources, descriptions, and identification", Dr. Hanneman proposed to give a numeric value to the types of luster. This never was put into practice, probably because of the more romantic connotations of the verbal descriptions.

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7.6: Sheen

Sheen is the effect caused by reflection of light from below the surface of the gemstone (whereas luster is on the surface). There are several terms associated with sheen (listed below). Their causes can range from inclusions to internal structures and interference to reflection and refraction.

Chatoyancy

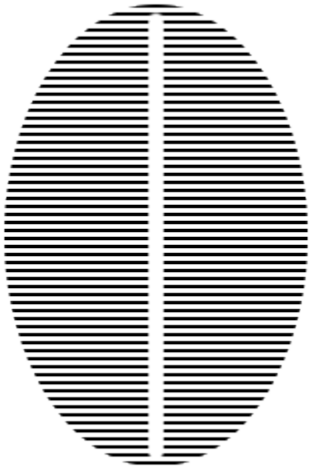


Figure 7.6.1***:*** *Formation of a cat's eye (streak at 90° to the inclusions)*

This type of sheen occurs on gemstones with parallel orientated inclusions, like fibers, needles, and hollow tubes. The effect of the reflection on these parallel arranged needles, fibers or hollow tubes is a light streak which runs at a 90° angle over the inclusions. In order for this effect to be seen, the gemstone needs to be cut en-cabochon.

Naming these types of gemstones is generally done with the suffix *Cat's-Eye*, as in *Alexandrite Cat's-Eye*.



Famous examples of this type of sheen are Chrysoberyl Cat's-Eye (or "Cymophane") and Tiger's-Eye (Quartz with asbestos fibers).



Other gemstones that may show chatoyancy are:

- Quartz
- Tourmaline
- Apatite
- Beryl
- Alexandrite
- Emerald

Asterism

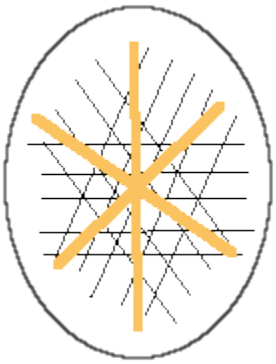


Figure 7.6.2***:*** *Formation of a star (streaks at 90° to the inclusions)*

Asterism, like chatoyancy, is caused by reflection on inclusions. However, the inclusions are arranged in different directions causing several streaks of light on the surface of the en-cabochon stone. In general, the inclusions which cause the stars are orientated parallel to the crystal faces. There can be 4-pointed, 6-pointed and 12-pointed stars.



Diasterism is asterism caused by transmitted light (from behind the stone) and can be seen in some Rose Quartz and Almandine Garnet. Asterism due to reflected light is named *epiasterism*, an example being 12-pointed Corundum.

Garnet may produce 4-pointed stars that intersect at 90°, whilst in Diopside the 4-pointed stars intersect at 73°.

Corundum usually forms 6-pointed stars (mostly due to rutile or hematite needles). Emerald has been reported to show a

6-pointed star.

You may also find in Corundum (usually in Thai sapphire) a 12-pointed star due to rutile and hematite inclusions following both the 1st order and the 2nd order prism. This is an example of *epiasterism* (due to reflected light).

Synthetic corundum may also show asterism. Usually, the stars are much better defined than their natural counterparts.

Some stones, especially corundum, have orientated inclusions but in insufficient quantities to show a star. These stones are generally facetted and occasionally you may see light reflected from small groups of such inclusions. This effect is termed ‘‘silk.

We describe stones that show asterism with the prefix *Star* as in *Star-Emerald*.

Some gemstones that may show asterism:

- Ruby (6-pointed)
- Sapphire (6-pointed, rarely 12-pointed)
- Rose Quartz (6-pointed)
- Spinel (4 or 6-pointed)
- Garnet (4 or 6-pointed)
- Diopside (4-pointed)

Iridescence

Iridescence is the play of color, or a series of colors, produced by interference or diffraction (or both), either when light is reflected from thin films (inclusions), twinning planes or from the unique structure of precious opal.

There are several types of iridescence that have their own particular causes:

- Labradorescence
- Adularescence (or Schiller)
- Aventurescence
- Opalescence

Labradorescence

Labradorescence is the effect seen in Labradorite (a Feldspar) and Spectrolite (a Labradorite found in Finland). It is caused by interference on the boundaries of lamellar twin planes, which are usual in Feldspars. Many Labradorites are carved to exploit this unique type of sheen.

Adularescence

This type of sheen is exhibited in Moonstone (another Feldspar), caused by reflection on Moonstone's lamellar twinning planes. The effect is a blue color floating just below the surface of the stone. Adularescence is also known as *Schiller*.

Aventurescence

Aventurescence is named after Aventurine Feldspar, which is also known as *Sunstone*. This type of iridescence is due to the play of color caused by reflection on tiny, thin inclusions of goethite and hematite (or both). This gives the stone a golden or reddish-brown color and specular reflections.

Opalescence

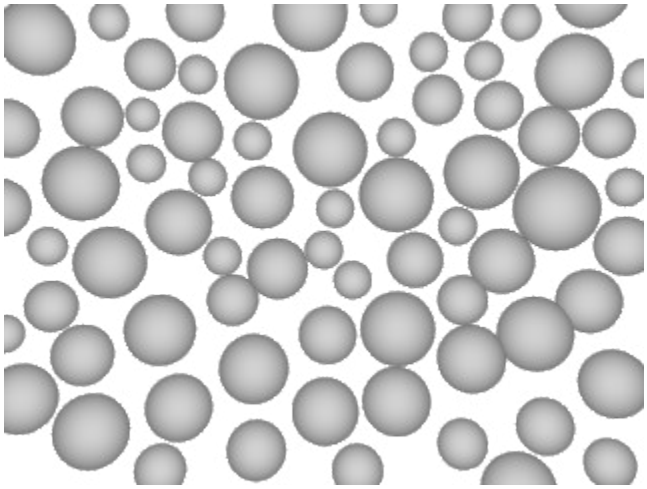


Figure 7.6.3*: Structure of opal (silica spheres)*

The causes of play of color in Opal were long uncertain until the invention of the electron microscope. This enabled scientists to see the unique structure of Opal at high magnification and to discover that Opal is made up of small spheres of silica.

In Opal, both interference and diffraction play a role in the play of color. Interference occurs when part of the light gets reflected from the surface of a silica sphere while another part gets refracted inside the sphere, being reflected again. Diffraction in Opal is the result of light hitting a gap between the spheres and then being split up into its spectral components.

In precious Opal, larger silica spheres of about 350 µm (micrometers) in diameter give off red flashes with changes in viewing angles. The smaller spheres result in green, blue or purple flashes which cannot increase in wavelength to give a red flash. Therefore, the sizes of the 'gaps', or 'voids', determine which color is seen.

This is the same way diffraction grating material functions, of which some spectroscopes are made.

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7.7: Brilliance

Basic

Brilliance is the degree of "brightness" of a gemstone, resulting from light reflected from and refracted off the crown and pavilion facets. Brilliance is an overall visual perception based on the physical laws of refraction and reflection.

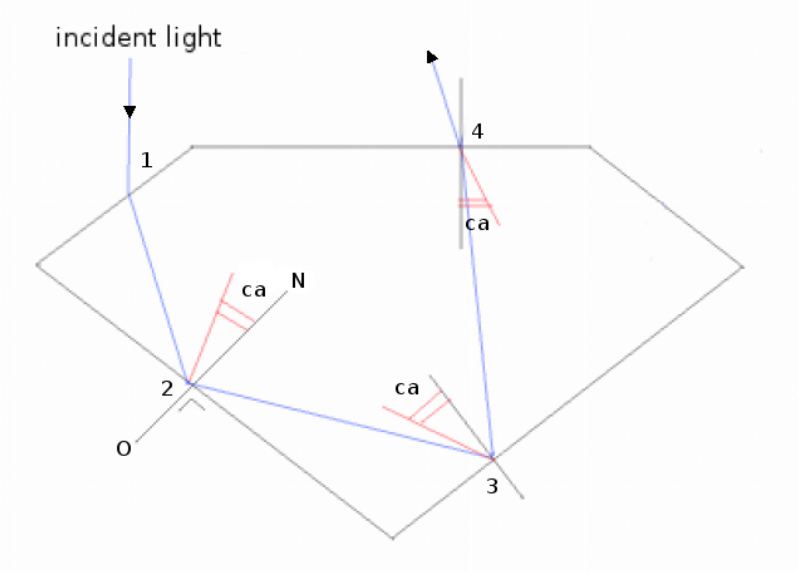


Figure 7.7.1: *Total Internal Reflection in a Diamond. Light reaching the facet at an angle larger than the critical angle will be reflected.*

When light hits the surface of a transparent optically denser medium (like a gemstone) it will be either reflected from the surface (bounced back) or partially refracted (bent and sent in another direction) inside the stone. When a light ray is refracted, it hits a pavilion facet and either is refracted out of the stone or reflected inside the stone depending on which angle the light ray approaches the facet (Fig.1, see its explanation below).

Every stone has an angle at which the light ray will either be refracted (sent along a different path) or reflected (bounced back). This angle is known as the critical angle and depends on the refractive index of the stone (how much the light ray is bent). The higher the refractive index, the smaller the critical angle.

When a light ray approaches a pavilion facet at an angle larger than the critical angle, it will be completely reflected inside the stone. The opposite dictates that light which falls at an angle smaller than the critical angle will be refracted outside the stone. This property is very important in the fashioning of a gemstone to create brilliance or "life". As every gemstone has its own critical angle, the design of the cut needs to be adjusted for the stone at hand.

Explanation of Figure 7.7.1: In this example, a brilliant cut Diamond is shown, having a critical angle ("ca") of approximately 24°26' (24 degrees and 26 minutes). The path the light travels (the blue line) is as follows:

1. light reaches the crown of the stone and is refracted (bent) inside the stone, bending towards point number 2
2. the light ray reaches a pavilion facet at an angle larger than the critical angle (ca), so it will be reflected (bounced) towards 3
3. at point 3, the light ray again reaches the pavilion facet at an angle larger than the critical angle so will be reflected towards 4
4. here, the light ray reaches the crown at an angle which is smaller than the ca, so it will be refracted out of the stone

Note

The critical angle is measured from an imaginary line named the *normal* (NO). This line is drawn at 90° to the surface of the facet at the point where the light reaches that facet.

In a well proportioned transparent stone, all light that enters the faceted stone through the crown will be trapped inside the stone for a while and then be refracted out of the stone through the crown. This behavior is known as Total Internal Reflection (often abbreviated as TIR) and it is the key ingredient in the design of a refractometer. It should be noted that **this unique phenomenon only occurs** on the boundaries of an optically denser medium (gemstone) and an optically rarer medium (such as air) **when light travels inside the denser medium**.

When a transparent stone is poorly cut (with either a too shallow or too deep pavilion), light will leave through the pavilion. Light bleeding through the pavilion facets causes a stone to appear either too light or too dark. Brilliance relies much on transparency, therefore stones with good transparency will show better brilliance when cut well.

Of course, in colored gemstones, other factors such as color zoning, pleochroism, etc also play a role in deciding how a stone needs to be cut for best optical performance.

Advanced

$$critical\ angle = \arcsin\left(\frac{1}{n}\right) \Rightarrow critical\ angle = \arcsin\left(\frac{1}{2.417}\right) \approx 24°26' \tag{7.7.1}$$

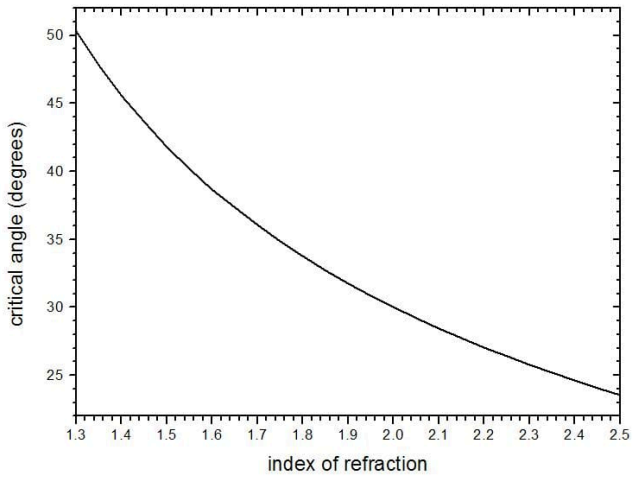


Figure 7.7.2*: Relationship between critical angle and index of refraction*

The critical angle can be calculated as the inverse Sine of 1 divided by n (the refractive index) of a gemstone. For Diamond with n = 2.417, the calculation will be the inverse sine of 1/2.417 (where 1 is the refractive index of air).

Note: the actual formula is arcsin(n2 / n1), but as we gemologists usually are only concerned with the critical angle between air and the gem, n2 = 1.

From the critical angle formula, the relationship between the refractive index of a gemstone and the critical angle becomes apparent. The higher the refractive index, the smaller the critical angle.

Related topics

- Refraction
- Reflection effects
- Math for gemologists

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7.8: Polarization

Polarization is a concept that is fairly easy to comprehend. It plays a key role in many concepts that are important to gemologists. Understanding the basics of polarization is vital in your studies.

Basics

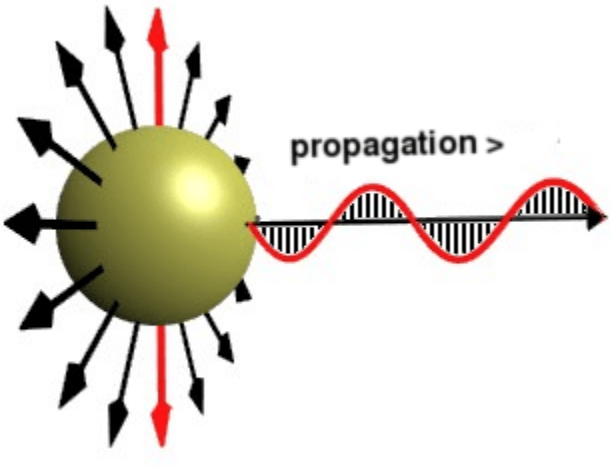


Figure 7.8.1*: Transversal light with light wave in N-S direction*

Light from the sun or a lightbulb is spherical, meaning that it transmits light in all directions.
If you were to follow one lightray in one direction (the direction of propagation), it would look like a circle with light being transmitted at an angle 90° to that direction. This is called transversal light. This transversal light is what is used as illustration for polarized light.

There are 3 causes of polarization, of which the first two are most relevant to gemology:

- Polarization by reflection
- Polarization by double refraction
- Polarization by scattering

Polarizing filters

A polarization filter lets through only light which vibrates in one direction (depending upon its orientation).
Polarizing filters are manufactured so that only a specific wave of transversal light can pass through the filter. This has a wide range of uses, from sunglasses to conoscopy and many other applications.

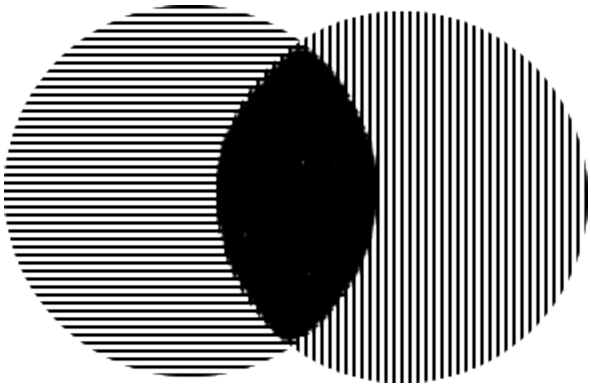


Figure 7.8.2*: Crossed polarization filters*

On the image on above the allowed pass-through directions are indicated by the black lines. The one on the left lets only light waves vibrating in the East-West direction pass through, while the one on the right allows only the waves that vibrate in the North-South direction to get through.
This must not be confused with a "venetian blind" or "picket fence" as that analogy is a very poor one and is incorrect (see wire grid polarizers).

When both filters are placed on top of each other (as indicated by the middle portion of the image), no light is able to pass through. This is because the first filter lets only the light that vibrates in the E-W direction to pass through and when that light reaches the second filter, it is not allowed to get through (because the second filter lets only the light vibrating in the N-S direction to pass through.
When two polarizers are set up this way, we named that "crossed polars" or "crossed polarizers", but not "crossed filters" as that is a different technique.

As you rotate the filter to other positions, other orientations will pass through. The produced light is what we call "plane polarized light", it only vibrates in one plane.

Advanced

Wire grid polarizers



Figure 7.8.3*: wire grid polarizer*

Wire grid polarizers are traditionally made from metal wires that are separated from each other at a certain distance. This distance is determined by the wavelength of the electromagnetic wave one wants to polarize. For visible light (with a wavelength between 700 and 400nm) the spacing is usually less than 200nm (0.2 microns).
When the spacing is increased, the filter starts to work as a diffraction grating. Plastic polarizers work in a similar fashion, the dichroic molecules are stretched creating a type of wire grid polarizer.

It needs to be understood that a ray of light (or any other electromagnetic wave) is polarized perpendicular to the direction of the wires. When the wires are orientated North-South, the electric component of the light will be polarized in the East-West vibrational direction. All other vibrational directions will be reflected or absorbed by the metal wires.
This is not very intuitive as more than often a "picket fence" or "venetian blind" analogy is used to describe the workings of a polarizer. In such an analogy it is described that the light vibrating in the direction of the open slits is allowed to pass through. That is, almost, correct for a venetian blind in a living room, but not when the spacing is less than the wavelength of the light. In fact, the venetian blinds let through unpolarized light (at least in the visible region).

Table 7.8.1*: Wire grid polarizer and its pass-through direction*

	
Polarizer	Internal metal wires enlarged

Polarization by reflection

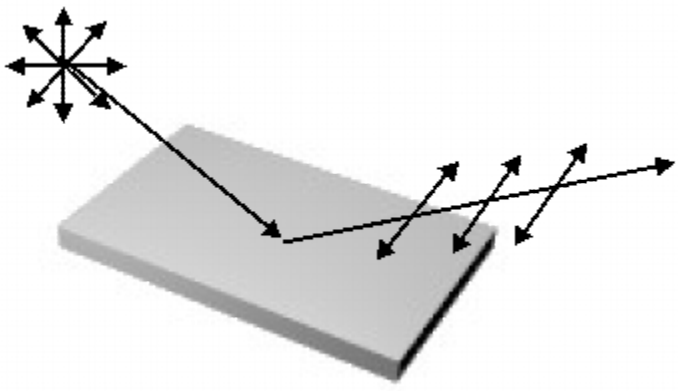


Figure 7.8.4: *Polarization of transversal light by reflection*

When light reaches an object, part of the light will be absorbed by the object (or refracted inside the object) while other parts of the light will be reflected by the object. This reflected light is partially to completely polarized, depending on the angle the light reaches the object. The polarization direction will be in the same direction as the surface of the object.
Sunlight striking the surface of water or a road are examples of reflected light. Most of the reflected light will be vibrating in East-West (E-W) direction, so polaroid sunglasses are orientated in North-South (N-S) direction to overcome the glare.
A Brewster Angle Meter makes use of this phenomenon.

Polarization by double refraction

When unpolarized light enters an anistropic gemstone at an angle other than the optic axis, that light will be split into two polarized rays, vibrating at right angles to each other. This is due to the double refraction properties of anistropic materials. On exiting the gemstone, these two polarized lights will combine again as unpolarized.
However, in some minerals (such as tourmaline), one of these polarized rays is completely absorbed by the mineral. This means that only one of the polarized rays will exit the mineral, and that ray will remain polarized. The phenomenon of absorbing light that travels in a certain direction is named selective absorption. The effect it causes is named pleochroism.
The first polaroid filters made were created from small grains of the mineral herapathite, which exhibits the same properties as tourmaline.

Crossed Nicols

Another way of separating the polarized rays to create polarized light outside a gemstone is by making use of the critical angle of a substance. In gemology, a device that does this is called a Nicol prism, and many textbooks still mention the use of "crossed nicols". A piece of Iceland spar (calcite) is cut in two at a diagonal to the c-axis and is then cemented back together with Canada balsam, with n_D = 1.537. Ordinary white light enters the Nicol prism and is split in two rays -- a slow ray (ordinary ray) and a fast ray (extra-ordinary ray). The ordinary ray will undergo Total Internal Reflection when it reaches the balsam. The extra-ordinary ray will pass through the balsam and leave the prism, polarized, on the other end.

Sources

- Introduction to Optical Mineralogy *3rd edition (2003), Prof. W.D. Nesse*
- Gemmology 3rd edition (2005) - Peter Read
- *Light Polarizing Body* (1940) - Patent by Charles H. Brown

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7.9: Pleochroism

Basic

Pleochroism is the change of color in colored anistropic (double refractive) gemstones when viewed from different directions or when viewed through plane polarized light. When light enters such a gemstone, it will be split into two rays that are perpendicular polarized. Each of the two rays travels at a different speed inside the gem, so they will be refracted differently.
Both rays will experience different forces inside the gemstone which cause the light to be absorbed depending on the path they travel. In other words, each ray will be absorbed inside the gemstone in different amounts.

The logical consequence of this is that each ray will be differently colored, depending on its direction. This result is named "differential selective absorption".

Uniaxial gemstones may have **two** associated colors. This type of pleochroism is termed "dichroism". Dichroic minerals always form in the hexagonal, trigonal, or tetragonal crystal systems.

Sometimes one encounters notations such as "ω = dark green" and "ε = pale green". These notations refer to the associated colors of each ray (the ordinary ray and the extra-ordinary ray respectively).

Biaxial gemstones may have three associated colors, and that type of pleochroism is termed "trichroism". Trichroic minerals always form in the orthorhombic, monoclinic, or triclinic crystal systems.

Although an incident ray of light is also split in two rays in biaxial gemstones, they may vibrate in three different directions. As a result, light will be absorbed differently in 3 directions.
For biaxial minerals, the notations are n_α, n_β and n_γ (relating to the X, Y, and Z vibrational directions).

We quantify the quality of pleochroism with a few simple (self-explanatory) phrases:

- Strong
- Distinct
- Moderate
- Weak
- None

The gemological tool used to observe this phenomenon is the dichroscope.

But one can also use the light emitted by a computer monitor to view pleochroism as a computer screen emits plane polarized light! If one rotates their gem in front of a white screen, like this one, pleochroism can be determined.

Sources

- Introduction to Optical Mineralogy *3rd edition (2003), Prof. W.D. Nesse*

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7.10: Color

Color is one of the most important (if not the most) factors that determine the beauty of gemstones.
While most other aspects in gemology are abstract and well defined, color is not. It is very subjective and the sensation of color differs from person to person as much as the visions of opponents in politics, religion or humor. To some, even the absence of color is preferred and the beauty is perceived from the optical properties a gem might posses (as the brilliance in diamond or reflection from rutile needles in Kashmir sapphire).

> **Note**
>
> Believe it or not, but the above white space is made up from 3 different colors (red, blue and green). Hold your loupe close to the screen and observe the powers of light.

Basic

> *"a phenomenon of light (as red, brown, pink, or gray) or visual perception that enables one to differentiate otherwise identical objects"*
>
> *Merriam-Webster Online Dictionary*

As can be read from the above definition of color, to humans color is a perception constant. Merriam-Webster defines perception as "*awareness of the elements of environment through physical sensation*".

From this can be concluded that the perception of color is a sensation that is different from person to person and is influenced by circumstances. People who are tired will most likely be less sensitive to color than those who are not. Photographers are well aware that objects have different colors in different lighting conditions. Furniture makers know that one should use only the fabric from the same dyed roll when covering a couch, as do tailors when making a suit as the circumstances in dying the fabric may change rapidly, but subtle, when the dye-bath is cleaned or needs a new mix (causing a phenomenon named metamerism).

The same applies to gemstones. Gems look different under changing lighting conditions and a gemologist should be very aware of this. Blue sapphires look best during afternoon hours, while rubies are at their best behavior before noon and in the evenings. Some gemstones even dramatically change their hue between daylight and incandescent light.

Causes of color

main article: Causes of color

What we see as color is merely the reflection of light from objects.
As white light (from the sun or other source) shines on a gemstone, some of the wavelengths will be absorbed by the gem while others are reflected from and/or transmitted through the stone. It is the combination of these left over ("residual") wavelengths that are collected at the back of our eyes (the retina) and interpreted by our brains, that defines the color of an object.
How exactly an object absorbs light is explained elsewhere.

In order for color to exist there must be 3 conditions met:

1. color vision
2. an object
3. light shining on an object

From these 3 requirements, one asks a few philosophical questions, as: does an object have color in the dark? The answer should, of course, be no. In fact, gemstones do not have color in light either, the color is produced by the interpretation of our eyes and brain. Which is different from one person to the other.
Under different lighting conditions, gemstones appear to have a different color, which can be easily demonstrated by shining different colors on a white object, like a wall. If you shine "white" light on the wall, none of the spectral colors are absorbed by the

wall and all is reflected back to your eyes. Making the wall look white. When one shines a green light on the wall, only the green portion of the spectrum can be reflected, hence the wall appears green.

Mixing colors

From a young age most of us are taught that if we mix red and green together, we get a black color (or at best a dark gray). The reason for this is that we were mixing paint. Mixing paint is *subtractive color mixing*.
For light, it works differently. When we would mix red light with green light, the result would be yellow light and this is termed *additive color mixing*.
Similarly if we mix red, green and blue paint together, the result will be black. But if we mix red, green and blue light together we get white light.

So when we think of light, we should completely forget about our Picasso minds.



Figure 7.10.1*: Additive color mixing of light*

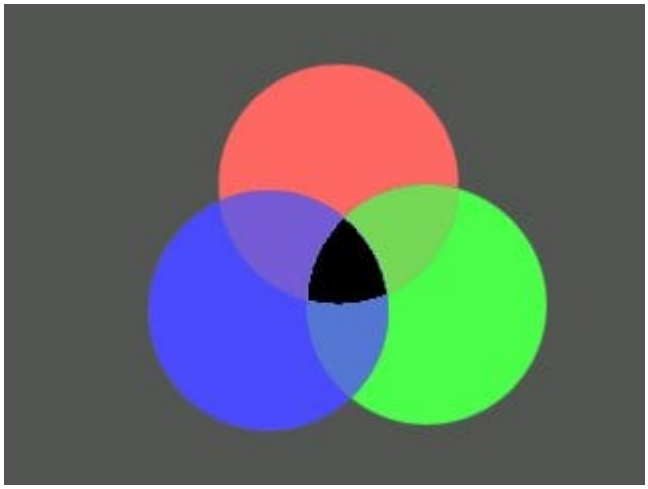


Figure 7.10.2*: Subtractive color mixing of paint*

With *additive* color mixing, we start with no light and add colored light. When we are in a dark room and we shine a red light (as from a torch) on a wall, that spot will appear red. Now when we add light from a green torch to it, we get a yellow spot on the wall. If we then at blue light to it, the spot appears white.

For *subtractive* color mixing, it works reversed. We shine white light on an object and the object absorbs portions of the light, subtracting that particular color from the light.

Lighting conditions

Proper lighting is crucial when attempting to color-grade gemstones. Selecting the correct lamps may greatly affect the color you perceive.

Daylight

Sunlight has color temperatures between 2,000 and 28,000° Kelvin. In the mornings the color temperatures are lower and look more red to yellow. Around noon the color temperature will be around 5.500° Kelvin and in the afternoon the color appears to be more blue with a high color temperature. In the evenings, the color temperature drops and the light will appear again more yellow to red. As one might suspect, different times of day will have an influence on the colors of gems.
The standard in grading colored stones is light at 5,500° Kelvin, that is when the light from the sun is mostly white.

Fluorescent lamps are produced to mimic this daylight from the sun and a wide range of good quality lamps are available. Pay good attention to the color temperature when buying one.

Incandescent light

Incandescent light is light from a hot object like a flame or a tungsten lightbulb. Usually, these lamps cannot be produced with a color temperature over 3,000° Kelvin and are therefore not suitable for the color-grading of gemstones.

Sources

- Ruby & Sapphire (1997) - Richard W. Hughes *Out of Print; Limited Availability*
- Secrets of the Gem Trade (2003) - Richard W. Wise
- Gemstone Enhancement (1984) - Kurt Nassau

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7.11: Color Grading

Color grading (colored gemstones)

The color grading system of the GIA separates "color" into 3 components which will be discussed in full below.

- Hue
- Tone
- Saturation

A typical notation for a colored gemstone in this system will look like the following sample.

B 5/2	The B stands for the hue (blue in this case), 5 stands for the tone and 2 indicates the level of saturation

When we judge colored gemstones we judge them "face up" (table up) while balancing the stone between our fingers in the palm of our hand. This lets the light be reflected in and out of the stone through the crown. When we judge reflected light, it is termed "key color" opposed to transmitted light which is named "body color" (viewed through the pavilion).
Diamonds are judged table down against a white background, but the focus of this system is on colored gemstones.

A very important ingredient in judging color is proper lighting. By convention, we use "northern skylight" when judging gemstones (or southern skylight when you live south of the equator).

Hue

When we use the term "color" in daily speech, we are actually referring to the "hue". Hue is the first impression we get when seeing color. This hue is modified by tone and saturation.
The GIA color grading system uses 31 different hues to describe the primary key color of a gemstone. These 31 hues are used to compare the color against the color of the gemstone.
For comparison purposes, several software programs have been created to replace the old plastic color swatches the GIA used to sell.

Color	Code	Name
	R	red
	oR	orangey red
	RO/OR	red-orange or orange-red
	rO	reddish orange
	O	orange
	yO	yellowish orange
	oY	orangey yellow
	Y	yellow
	gY	greenish yellow
	YG/GY	yellow-green or green-yellow
	styG	strongly yellowish green

	yG	yellowish green
	slyG	slightly yellowish green
	G	green
	vslbG	very slightly bluish green
	bG	bluish green
	vstbG	very strongly bluish
	GB/BG	green-blue or blue-green
	vstgB	very strongly greenish blue
	vslgB	very slightly greenish blue
	B	blue
	vB	violetish blue
	bV	bluish violet
	V	violet
	vP	violetish purple
	P	purple
	rP	reddish purple
	RP/PR	red-purple or purple-red
	stpR	strongly purplish red
	slpR	slightly purplish red
	R	red
	Pk	pink (exception)
	Brn	brown (exception)

Tone

Tone is the lightness or darkness in a gemstone.
There are 11 degrees of tone in the GIA color grading system, but only 7 of them are actually used (2 through 8).

Tone	Scale	Name
	0	colorless or white
	1	extremely light
	2	very light
	3	light
	4	medium light
	5	medium
	6	medium dark
	7	dark
	8	very dark
	9	extremely dark
	10	black

Hsv-blue.jpg

Figure 7.11.1*: Tone Scale*

Although from the tone scale given above one could think of midrange tones (such as 5) to be gray, this is not the case. Instead one should think of it as white or black mixed in with the pure hue.
In the image above, a pure blue hue is mixed in with various amounts of white (from 2 to 5) and various amounts of black (5 to 8).

Gray is a modifier of saturation, not of tone.

Saturation

Saturation is the brightness (or purity, intensity) of a hue. The purer the hue, the higher grade it will get on the saturation scale.

The saturation scale goes from 1 to 6. Lower grades (1 to 3) can have a gray or brown modifier, while in grades above 3 these modifiers are absent.
Cool colors, like green and blue, have a gray modifier in low saturation. The warm colors (red, orange and yellow) have a brown modifier. Any stone that doesn't have a gray or brown modifier will at least be a 4 on the saturation scale.

Saturation scale with descriptions:

1. grayish (brownish)
2. slightly grayish (brownish)
3. very slightly grayish (brownish)
4. moderately strong
5. strong
6. vivid

The descriptions are only used in verbal communications.

		Figure 7.11.2*: Saturation scale for me*
		
		1 | 2 | 3 | 4
		Saturation blue.gi

Sources

- *Secrets of the Gem Trade* (2003) - Richard W. Wise

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7.12: Causes of Color

Basic

In general, color is caused by the absorption of certain wavelengths of light by a substance (as a gemstone) while permitting other wavelengths to pass through the substance unaltered. The net result of the wavelengths that pass through the gem give the final color to the gemstone.

In order to see color we need at least 3 variables:

- Light
- A substance
- Vision (the eye)

When any of them is absent, we can't see color. For instance, your red sweater will have no color in the dark as there is no light for the sweater to absorb.

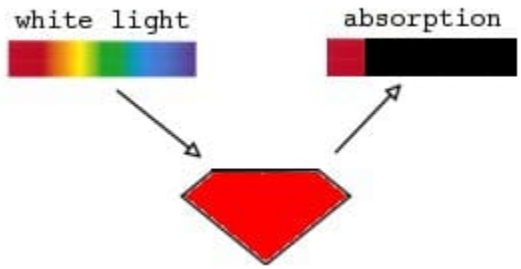


Figure 7.12.1*: Absorption of all wavelengths except red*

White light is a mixture of the 7 spectral colors (visible in a rainbow): red, orange, yellow, green, indigo, blue and violet. Each of these colors travel at a certain wavelength (about 700nm for red and 400nm for violet) and carry a specific amount of energy. When a substance absorbs all the spectral colors (the colors of the rainbow) except red, the residual color is red. Therefore the net result will be red. If all colors except red and blue are absorbed, the residual color (net result) will be a purple gemstone.

In total there are about 16 million combinations that can produce color.

Absorption of light usually results in the transformation of light energy to heat. That is why frigidaires are white; white substances don't absorb light so they are very effective at keeping heat away.

Table 7.12.1*: Coloring elements*

Element	Colors
Titanium	Blue
Vanadium	Green / Color change
Chromium	Red - Green
Manganese	Pink
Iron	Red - Green - Yellow
Cobalt	Blue
Nickel	Green
Copper	Green - Blue

Absorption of wavelengths (colors) happens because certain elements absorb the energy of those wavelengths. The main elements that absorb color are the "transition metal" elements. These transition metals have partially filled d-shells (opposed to fully filled shells) and some of the electrons in the d-shells are unpaired.

When a wavelength carries enough energy to raise an unpaired electron to a higher energy state, the energy of that wavelength is completely absorbed by the electron and the light energy is usually transformed to heat when the electron falls down to its original (ground) state. This means that that particular wavelength (or color) is removed from the spectrum, or better "absorbed".

The energy required to raise an unpaired electron to a higher energy state (and so cause absorption) is far less than the energy required to raise a paired electron. The energy in visible light is not enough to raise a paired electron, but it can raise the unpaired electrons that reside in the d-shells of the transition metal elements. That is why the transition elements are also named the "coloring elements" or "coloring agents". Besides the transition metal elements, some rare earth metals also act as coloring elements.

The coloring agents can either be part of the ideal chemical makeup or occur as impurities in the crystal.
We divide minerals into two groups, depending on this.

- Idiochromatic - minerals that are colored by a coloring agent that is part of the chemical formula (for instance malachite)
- Allochromatic - the coloring agents are not part of the ideal chemical composition (such as emerald and ruby)

Although the theory of transition metal elements serves as a good basic understanding for the causes of color, there may be other mechanisms at work. Some elements work together to form color (the molecular orbital theory) while in other cases the absence of an electron or an element at a particular place ("site") in the crystal creates a color center.
What all the theories have in common is that some energy from incoming light (wavelengths) is absorbed and the residual colors (wavelengths) determine the final color of the gemstone (or any other substance).

Advanced

The causes of color can be divided into 4 different theories:

1. The Crystal Field Theory
    - Transition metal compounds (malachite, almandine) - idiochromatic
    - Transition metal impurities (ruby, emerald, citrine, jade) - allochromatic
    - Color centers (amethyst, maxixe-beryl)
2. The Molecular Orbital Theory
    - Charge transfer (sapphire, iolite)
3. The Band Theory
    - Insulators (glass)
    - Conductors (metals)
    - Semiconductors (galena)
    - Doped semiconductors (diamond)
4. The Physical Properties Theory
    - Dispersion (Fire in diamond)
    - Scattering (moonstone, cat's eyes, stars)
    - Interference (iridescence, opal)
    - Diffraction (opal)

The Crystal Field Theory

The crystal field theory describes colors originating from the excitation of electrons in transition elements (either idiochromatic or allochromatic) and color centers.

When a transition metal ion has a partially filled d-shell, the electrons in the outer d-shell orbit the nucleus unpaired (or at least some of the electrons do). The surrounding ions of the crystal lattice create a force (a "crystal field") around such a transition element and the strength of those fields determine which energy levels are available for the unpaired electrons. Such a system of energy levels depends on the strength and nature of the bonding in the lattice as well as on the valence state of the transition element. These are different in every crystal.

As energy and energy levels are quantized, the electrons need a specific amount of energy to "jump" from its ground state to a higher energy level. The complex calculations that determine which energy levels are available for the electron to excite also provide a few selection rules which exclude some levels for excitation.

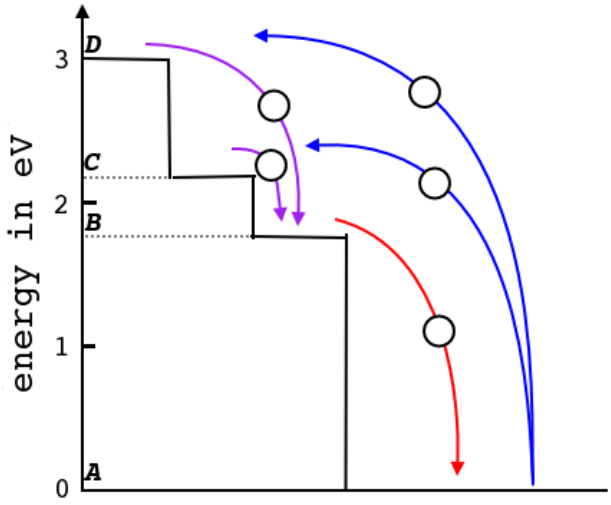


Figure 7.12.2*: Absorption in ruby*

In ruby, Cr^{3+} substitutes some of the Al^{3+} ions in the Al_2O_3 lattice. As the chromium is not part of the ideal make-up, ruby is said to be allochromatic. The crystal field around the chromium impurity makes a few, quantized, energy levels available to the unpaired electrons. These are presented as levels B, C and D. However selection rules determine that level B is not available for excitation in this case.

Levels C and D correspond with energies of respectively 2.23 eV and 3 eV. The energy needed to jump to level C (2.23 eV) corresponds with yellow-green light and level D (3 eV) corresponds with violet light.

This means that when white light enters a ruby, yellow-green and violet light will be absorbed by the unpaired electrons and these electrons now have sufficient energy to be excited to levels C or D. The residual colors that are not absorbed determine the red color of the ruby.

The same selection rules also forbid the excited electron to fall back to their ground states (A), but must instead first fall back to B. When the electrons in level B deexcite to their ground state, emission of red light occurs (fluorescence) which gives an extra glow to the already red color caused by the absorption of the yellow-green and violet portions of white light.

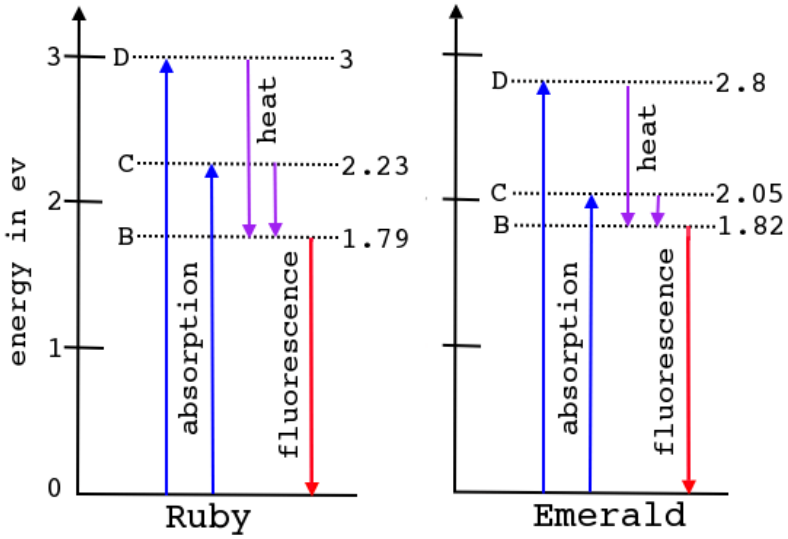


Figure 7.12.3 *: Schematic overview of energy levels in ruby and emerald*

For emerald, which allochromatic color is also caused by a Cr^{3+} impurity, the mechanism is similar but the crystal field from the surrounding elements has less strength and causes a shift in absorption bands. The D level is lowered to 2.8 eV and the C level is lowered to 2.05 eV but the B level is almost the same (1.82 instead of 1.79 eV).
The result is that emerald absorbs most violet and red portions of visible light, leaving a dominant blue-green transmission with a red fluorescence.

Alexandrite, a variety of chrysoberyl, is also colored by a Cr^{3+} impurity. The absorption scheme of alexandrite is between that of ruby and emerald and the intensity of the incident light determines the color of the alexandrite. Natural daylight is richer in blue-green while incandescent light has more red in its spectrum. This causes the alexandrite to be blue-green (emerald like) in daylight and red-violet (amethyst like) in incandescent light.

Vanadium (V^{3+}) causes the same "alexandrite" color change effect in natural and synthetic corundum.

Allochromatic colors caused by transition metal impurities

The mere occurrence of a transition metal impurity does not necessarily cause the color in a gemstone. Apart from the need of a specific valency, the ion must have to be responsible for absorption, other mechanisms (such as color centers and charge-transfer) may be more dominant.
Like certain impurities may be responsible for different colors, as red and green for chromium, other impurities may also cause the same color (like vanadium in emerald).

Idiochromatic colors caused by transition metal constituents

The crystal field theory described above also applies to minerals that have a transition metal ion in its ideal chemical composition.

Color centers

Unpaired electrons on non-transition metal ions may also produce colors in certain circumstances. This can either happen due to misplacement of an ion (and an unpaired electron taking its vacancy), or due to the displacement of an electron from (natural or artificial) radiation.
In both cases, a "color center" is created and the unpaired electron can be raised to higher energy levels through the absorption of incident light as with unpaired electrons of the transition metal ions. In the first case (an electron substituting a misplaced ion), the color center is an "electron hole center" and in the latter case it creates a "hole color center".

Electron color centers

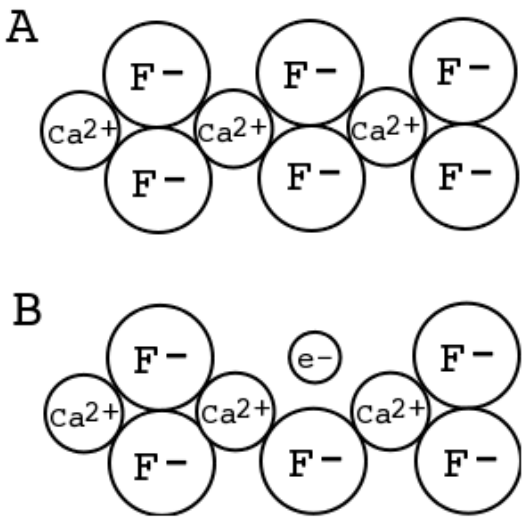


Figure 7.12.4*: Electron color center in fluorite*

Fluorite is most often used to describe the mechanism of an electron color center. The purple color of fluorite is caused by the absence of a fluorine (F^-) ion and an electron is trapped in the vacancy it leaves behind.
There are various reasons why the fluorine ion is missing from a particular site in the crystal lattice. Among those are an excess of calcium and radiation. either during or after growth of the crystal. This creates a so-called "F-center" (or "Farbe center" - Farbe is the German word for color) and a free electron from the pool of unpaired electrons in the crystal (see Band Theory) is trapped in the vacancy. This unpaired electron can then be raised to the now available, higher energy levels by the absorption of energy in photons and similar crystal field rules of absorption and fluorescence, as described above, are in effect.

The fluorine ion is usually displaced and creates an interstitial in the lattice, a so-called "Frenkel defect", meaning that there is an ion at a particular site in the lattice where it normally would not be. This displaced fluorine ion does not play a role in the development of color (only the vacancy it leaves behind does).

The term "electron color center" refers to the fact that there is a "free" electron where it normally wouldn't be.
Situation A in the image shows the ideal configuration of fluorite, while situation B shows the electron that is trapped in the vacancy left behind by the displaced fluorine ion.

Hole color centers

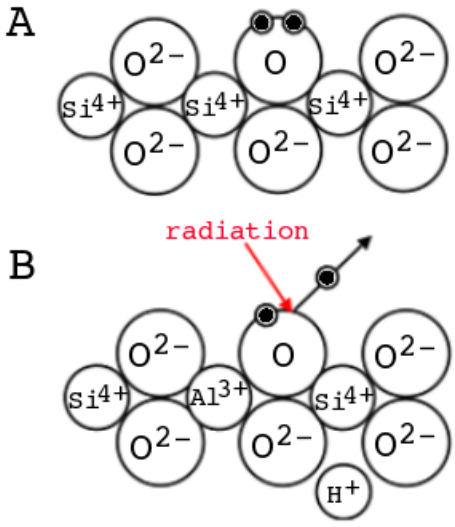


Figure 7.12.5*: Hole color center in smokey quartz*

Hole color centers are usually illustrated by smokey quartz as in the image on the right.
In quartz (SiO_2) some silicon ions with a valence state of 4+ are substituted by aluminum ions with a valency of 3+. In order to keep electroneutrality, a hydrogen atom (or Na^+) will be present nearby. This causes the forces on the electrons of the oxygen atoms to be weakened and radiation (X-ray, gamma rays etc.) can remove one of the weaker bonded electrons of the oxygen atoms. This leaves a hole (one electron is missing) and different energy levels become available to the now unpaired electron on the oxygen ion.
The crystal field theory now applies for the remaining, unpaired, oxygen electron and the resulting color is a smokey brown to which smokey quartz owes its name. The displaced electron will be trapped at other sites in the crystal lattice and it doesn't contribute to the color making scheme.
The substitutional aluminum ion acts as a "precursor" and is vital to the mechanism.

In amethyst the workings are similar, but the precursor is ferric iron (Fe^{3+}) and produces the typical purple color.

The term "hole color center" refers to the missing electron, leaving behind a hole.

If the crystal is heated (around 400° C. for smokey quartz and ± 450° C. for amethyst), the displaced electron is freed from its trap and returns to its original site, traveling as paired electrons again. The color of the crystal will then return to its original color (usually yellow ("citrine") or green ("prasiolite") for amethyst and colorless for smokey quartz). After re-irradiation, the hole color center can be reproduced and as long as the crystal is not overheated, this process can be repeated infinitely.
The process of heating the crystal and destroying the hole color center is named "bleaching".

The Molecular Orbital Theory

The molecular orbital theory describes the paths (orbitals) electrons travel when multiple atoms (two or more) combine chemically. In order for atoms to combine to molecules, they must share or exchange electrons.

Most diagrams and textbooks used to explain orbitals in fundamental chemistry (and gemology), show the orbitals or movements of electrons in 2-dimensional rings. Although that suffices for a basic understanding, the orbitals are 3-dimensional and electrons move in complex clouds.
An in-depth explanation of those orbitals can be very useful in describing this theory but it is a very complex topic and goes beyond the realm of gemology.

Instead, we will focus on the different types of bonds that can occur between atoms.

1. Ionic bonding
2. Covalent bonding

While both these bonds have different characteristics, mostly they both play a role in the chemical bonding of gemstones and are directly related to the *electronegativity* of the different elements that make up the chemical formula of a gemstone.
It is only the electrons in the outer shells of atoms that play a role in both ionic or covalent bonding.

Electronegativity

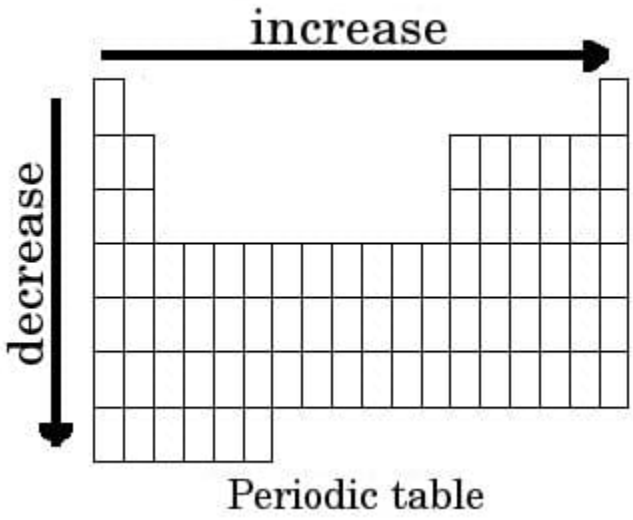


Figure 7.12.6*: Electronegativity scale*

Electronegativity refers to the force at which certain elements attract each other. One of the ways the periodic table of elements is arranged is by their electronegativity. In general, the elements in the upper right corner have a stronger electronegativity than the ones in the lower left corner.
As different elements try to combine to form molecules, the elements that have the highest electronegativity are the most greedy and take precedence over the elements with a lower electronegativity.

When there is a large electronegativity difference between two elements, the element with the higher electronegativity will grab the electrons from the other element and this causes a very strong bond between those two elements.
The "greedy" element will have an extra negative charge (because it grabbed negative charged electrons from the other element) and thus *polarization* between the two elements occurs. This polarization (one element will have a positive charge and the other a negative charge) acts like a magnet and the two elements will be very close to each other. In other words, they form a very strong bond and there will be an exchange (donation and receiving) of electrons. This is referred to as *ionic bonding*.

However, if the electronegativity difference is very low or the electronegativity is the same, the bonds are not as strong and the electrons in the outer shells of the atoms (elements) are shared between the different elements and those electrons can travel freely (but according to certain rules) between the two elements. This type of loose bonding is named *covalent bonding* and the atoms that make up the molecule are spaced further apart than in ionic bondings.
Covalent bonding plays a large role in the formation of color as the energy required to exchange the electrons causes absorption. *Charge transfer* is a common term to describe the continues exchange of electrons in covalent bondings when energy is applied to the molecule.

The main difference between ionic and covalent bondings is that in ionic bondings there is a *donation/receiving* of electrons, while in covalent bondings there is a *sharing* of electrons.

Charge transfer

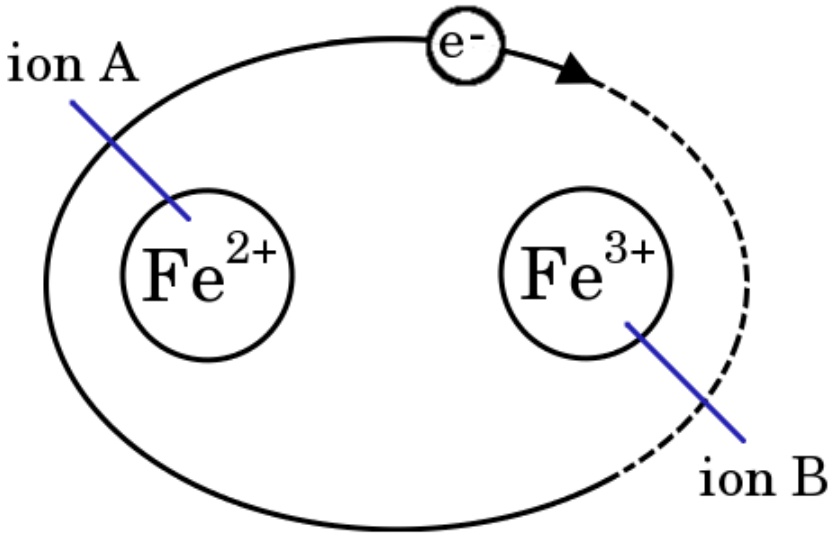


Figure 7.12.7*: Charge transfer in Iolite*

Different elements (especially the transition elements) can exist in different valency states. When those charged atoms (ions) form covalent bondings, some electrons in the outer shells can travel between those two ions. This results in a **charge transfer** between those two ions and can only happen through the absorption of energy. When the energy required for that transition is equivalent to the energy in the visible range (or near that) of light, it will result in color.

In the case of iolite it is believed that the color is caused by the charge transfer between Fe^{2+} and Fe^{3+} ions. The Fe^{2+} ion has one more electron in its outer shell than the Fe^{3+} ion. That electron is attracted to the Fe^{3+} ion and when the electron orbits the Fe^{3+} ion, that ion will become an Fe^{2+} ion. The original Fe^{2+} ion will then become an Fe^{3+} ion and the process repeats.

The usual notation for such a transfer is:

$$Fe^{2+} + Fe^{3+} \rightarrow Fe^{3+} + Fe^{2+} \tag{7.12.1}$$

For sapphire the workings are similar, but the transition is between Fe^{2+} and Ti^{4+}. Although there are many other elements that could play a role in the coloration of sapphires, the general notation for (blue) sapphire is:

$$Fe^{2+} + Ti^{4+} \rightarrow Fe^{3+} + Ti^{3+} \tag{7.12.2}$$

The Band Theory

The band theory was originally developed to explain electrical conductivity in metals. Later this theory was further developed with quantum mechanics and with that it could also explain colors in materials (such as gemstones).

Electrical conductivity depends on the free travel of negatively charged electrons through a material. In order for an electron to travel through a solid (like a metal or a crystal), there should be room for the electron to travel.
Imagine you are in a room full of people and you would want to walk to the other end of the room. In a fully packed room, you could not cross it as there are too many people in it. Now imagine that there is a balcony above the room where there are no people. When some of the people would have enough energy in there body to jump onto the balcony, those people now have freedom to move. While those people move to the balcony, they leave spaces behind in the room so the rest of us have more space to move around.
Of course for people to jump onto the balcony, they need the energy to do so. If they don't have that energy, they will just fall back. So there is a gap between the room and the balcony they need to bridge.
The same thing applies to electrons in a solid.

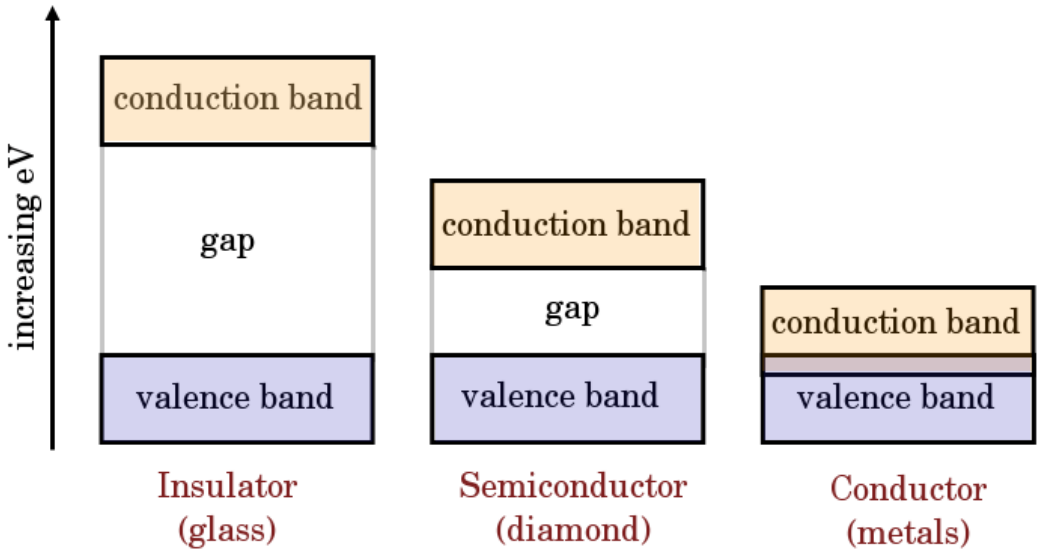


***Figure \(\PageIndex{8}\)**: The band (gap) theory illustrated*

In previous theories, the focus was on single or two charged atoms (ions). Some electrons are in filled energy levels around the atoms and are very localized in the sense that they have a very strong binding force to the nucleus. Yet the electrons in the outer (unfilled) shells can play a role in binding with other atoms, either through ionic or covalent bondings. Those electrons are named *valence electrons* and are loosely bound to the nucleus. In reality, there is a very large number of valence electrons in a crystal (a multitude of billions per cubic millimeter).
If we would throw all those looser bound valence electrons in a pool of electrons we would get an imaginary pool of valence electrons. That "pool" is named the **valence band**.
As the valence band is completely filled with electrons, no travel of electrons is possible. So there can be no electrical conductivity. If the electrons would have enough energy to break from this valence band and enter the **conduction band** (the balcony), then electrical conductivity will be possible. In various materials, the **band gap** (the distance between the ground floor and the balcony) differs.

Depending on the energy required for an electron to overcome this gap, we divide materials into three categories:

1. Insulators (large gap with no electrical conductivity)
2. Conductors (small to no gap to overlapping energy levels with a good electrical conductivity)
3. Semiconductors (intermediate between insulators and conductors)

In insulators, the gap is so large that under normal conditions (room temperature) there is not enough energy for an electron to bridge the large gap between the valence and the conduction band. As a consequence materials with a large gap will be electrical insulators as well as colorless. The last part (colorless) is logical because the solid cannot absorb energy from visible light. Glass is an example of a good insulator.

In conductors (such as metals) there is a very small band gap or no band gap at all (usually the band and conduction gaps overlap). Therefore electrons can easily be in the conduction band. As little energy is required for an electron to go from the valence band to the conduction band, these materials will be opaque because all of the energy in visible light will be absorbed. The ideal situation would result in an opaque black material, but other forces may turn it into a colored opaque material (such as yellow for gold).

Semiconductors are intermediate between the two states mentioned above and we divide semiconductors into two categories:

1. Intrinsic semiconductors (pure elements)
2. Extrinsic semiconductors (doped elements)

Doping means that there are impurities with a different valence state in the crystal lattice, like in allochromatic gemstones.

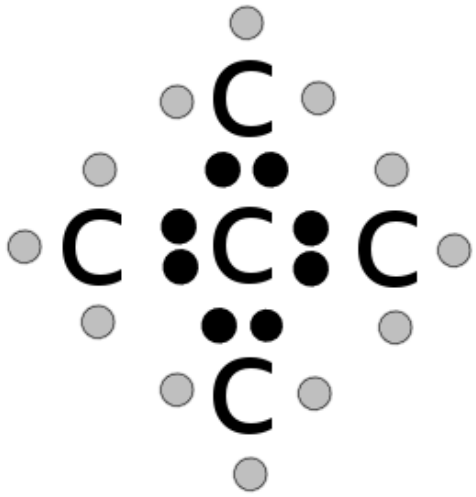


Figure 7.12.9*: Lewis dot structure of diamond.*

Intrinsic semiconductors with a large band gap usually behave as insulators (such as diamond). Every carbon atom in the diamond structure has 4 valence atoms and they try to combine with 4 other carbon atoms to form a tetrahedral molecular structure. This means that in a pure diamond structure the valance band is fully occupied and the conduction band is empty (so no electrical conduction is present). Yet if we could find a means to make room in the valence band and/or to occupy the conduction band, then the diamond could be an electrical conductor.
For this, we would need an impurity to substitute for a carbon atom in the "ideal" diamond structure.

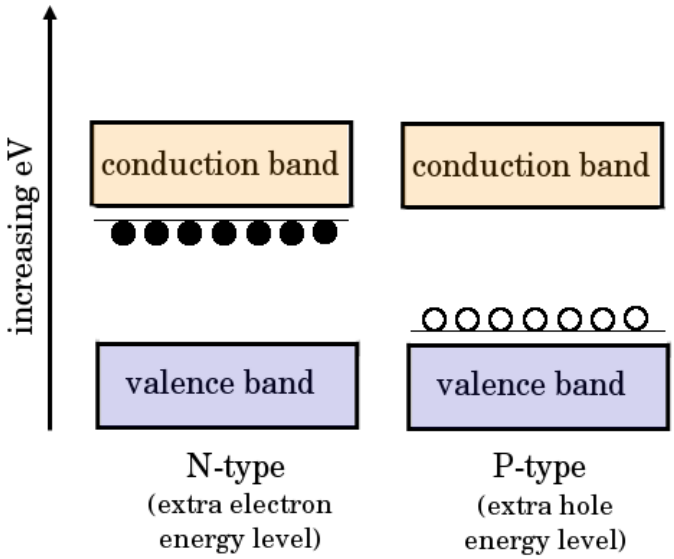


Figure 7.12.10*: Two types of doped semiconductors*

If we would replace a carbon (C) atom with a nitrogen (N) atom, which has 5 valence electrons instead of 4, then we would have one electron too many. That excess electron would create an extra energy level inside the band gap below the conduction band. Some electrons in this extra electron energy level can now be excited into the conduction band. This type of a *doped semiconductor* is named an N-type semiconductor (N after negative charge from the extra electrons). Yellow type IIa diamond is an example of this type.

The opposite works as well, if we introduce boron (B) in the lattice, which has 3 valence electrons, the diamond would have a positive charge and it would create a hole in the energy gap (another term for a band gap). An electron from the valence band is

excited to fill the hole and that creates a hole in the valence band. A neighboring electron in the valence band will fill that hole and the hole seems to be moving through the valence band, which creates conductivity. This type is named a P-type semiconductor (P after the positive charge created by the hole). Blue type IIb diamond is an example of this. Irradiated blue diamond does not conduct, so a distinction can be made between them.

The Physical Properties Theory

Although the previous theories describe the causes of colors originating from electron interactions, there are a few other ways colors can be created. Mostly they show as patches of colors caused by dispersion, scattering, interference and/or diffraction. All these phenomena are explained in other chapters.

Sources

- Kurt Nassau (1978) - The origins of color in minerals
- The Physics and Chemistry of Color, 2nd Edition,Kurt Nassau (2001)

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7.13: The Phenomenon of Color Change

What is colorchange?

There are a number of effects that account for a change in color in any material. There is the Alexandrite effect, Usambaru effect and many luminescence effects like fluorescence, triboluminiscence, chemoluminiscence, thermoluminescence, and phosphorescence. The Alexandrite effect together with fluorescence and phosphorescence are maybe the most well-known effects. One by one the effect is described and explained.

1. Alexandrite effect

Also known as colorchange effect or color shift effect. One can debate for a long time what would be the right term to use when watching an alexandrite change color when viewing it in daylight as a green stone to red incandescent light. This is the most remarkable change ever seen. This does not only happen in alexandrite, but in many stones: Sapphires, triphilyte, granates, apatite, monazite, etc etc. Some have a strong effect like with some alexandrites others have a very week effect that can hardly be seen.

The basis of the change in color lies in the color of the light that is used. Part of the light is absorbed and part is reflected. The color is depending on our perception, the absorption and the type of light used. Daylight has more blue in its spectrum than incandescent light. Alexandrite has a big absorption in the green part of the spectrum and reflection in the blue and the red part. If viewed in daylight the red portion of the spectrum is absorbed by the stone and the blue and green part is reflected to the observer. Therefore the stone appears green. If incandescent light is used this is more yellow. We as humans correct the color of things by our mind so the paper that looked white in sunlight still looks white in incandescent light. But in reality is a bit yellowish. Never the less there is less blue in the spectrum. So the reflected light also has less blue in it. So the reflection to the observer is less blue and the same amount of red. The result is that there is not enough blue reflected to mix the perceived color to green. So the perceived color is more reddish. The less blue is in the light the more red the stone appears.

To be added: example graphs of spectrum of various light sources, absorption spectrum of alexandrite, schematic representation of the text.

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7.14: Refraction

Basic

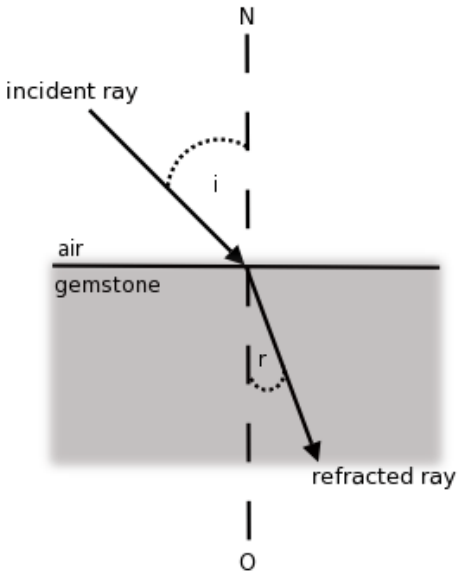


Figure 7.14.1*: Refraction of a light ray*

Refraction is the change of direction in which light travels as it passes from one substance to another that has a different optical density (as from air into a gemstone).

Optical density is a property that manifests itself in the slowing down of light, i.e. the higher the optical density, the lower the speed of light. This change in speed causes light to bend (refract), as can be seen when a spoon is put into a glass of water. Because light travels slower through water than air, the spoon appears to be bent. This bending of the light is referred to as refraction. Refraction of light as it passes from one medium to another can be calculated from Snell's Law. (see below).

In Fig.1, the angle of incidence is indicated with **i** and the angle of refraction by **r**. When light travels from air to an optically denser medium (like a gemstone), it will hit the surface at an angle to an imaginary line named the *normal* (NO). The normal is a line passing through the point of intersection that is perpendicular to the surface. It will then partially enter the stone (other parts will be reflected). Due to the slowing down of light inside the stone, it will bend (refract) **towards** the normal.

The opposite of this is also true. Light that travels from a gemstone into an optically rarer (or less dense) medium such as air will bend away from the normal. The angle at which light is now refracted out of the stone is the same as the angle of incidence, which means it will continue along the same path as on incidence (when it entered the stone).

A gemstone's index of refraction may depend upon the wavelength of incident light (wavelength may change as light enters the gem). Then, since different wavelengths of visible light correspond to different spectral colors, the refractive index may differ slightly for each spectral color.

In gemology, yellow light is used as the main source for measuring the refractive index of a gemstone. Yellow light was chosen because in the early days of gemology it was easily produced by salt (sodium) in a flame and was an inexpensive means of producing monochromatic light. The wavelength of sodium light lies at 589.6nm, known as the Fraunhofer D-line. When **n** is used to describe the index of refraction, we use $\mathbf{n_D}$ to indicate the refractive index when measured with sodium light. This is commonly abbreviated as RI (refractive index).

The instrument of choice to obtain the refractive index of a gemstone is the refractometer.

The math behind Snell's laws of refraction

Refraction follows the laws of Snell, which state that:

- The sine of the angle of incidence (i) and the sine of the angle of refraction (r) are related to each other at a fixed ratio. This ratio is known as the *index of refraction*. The ratio depends both on the wavelength of the light and on the substances in which this light travels.

$$Index\ of\ refraction = \frac{\sin i}{\sin r} \tag{7.14.1}$$

- The incident ray, the refracted ray and the normal all lie in the same plane.

The index of refraction is abbreviated with the letter **n**. As the index of refraction also relates to the velocity of light, one could write:

$$n = \frac{velocity\ of\ light\ in\ air}{velocity\ of\ light\ in\ medium} \tag{7.14.2}$$

Advanced

Causes of refraction

Explaining the causes of refraction is not an easy task, yet a pseudo-scientific approach is given below. It is based on two principles:

1. Quantum electrodynamics (to explain the slowing down of light in a denser medium)
2. Huygens' principle

Quantum electrodynamics

$$f = \frac{V}{\lambda} \tag{7.14.3}$$

Velocity (V) of light is dependent on wavelength (λ) and frequency (f). Frequency is the number of crests that pass a given point in one second and is expressed in hertz (Hz).

The frequency of light is the same in every medium. This means that if the velocity of light changes, the wavelength must also change. As a consequence, light traveling from air into an optically denser medium will travel at shorter wavelengths inside that medium.

At the atomic level, an incident photon is absorbed and will make an electron cloud vibrate at the frequency of the wave and emit that energy in the form of a photon with a delay, which has a net result of slowing down. The emitted photon is newly created and thus is not the same photon that was absorbed. Since the electron cloud vibrates at the same frequency as the incident wave, the frequency of the emitted light wave will not be altered. In order to keep the equation intact, a drop in velocity must mean a decrease in wavelength.
Thus both the velocity and the wavelength of a light wave decrease when entering a denser medium.

The relationship between wavelength and speed of light

Figure 7.14.2*: Speed of light and wavelength*

Light in air travels at approximately 300,000 km/second. When it enters an "optically denser medium", this light will slow down. The amount at which it slows is related to the index of refraction of that material.

Assuming the RI of the material = 2, then the light (coming from air) will be slowed down to 150,000 km/second, or half the speed

of the light in air.

As there is also a direct relationship between the speed of light and wavelength, the wavelength will decrease as well. This means that a beam of red light (with a wavelength of about 700 nm) will travel at a wavelength of 350 nm inside the material with index of refraction = 2. As the frequency remains the same, the color of the light wave is not altered.

Wavefronts (Huygens' principle)

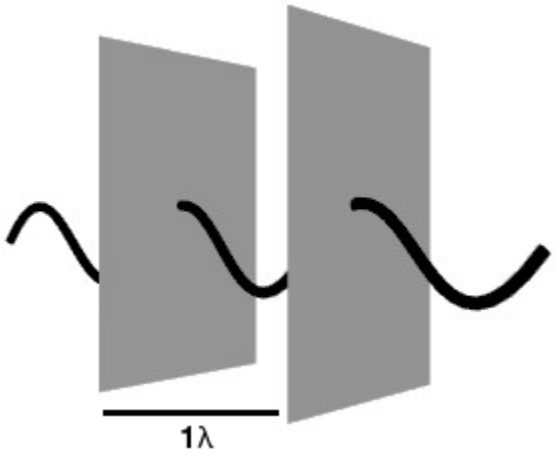


Figure 7.14.2 *: Two wavefronts on a single wave, each one wavelength apart*

Light propagates from a single source in all directions just like a pebble thrown into a pond creates waves around the center of impact. These waves (the wrinkles in the water) are at a certain distance from one another (wavelengths). The direction of propagation is perpendicular to the wave, and the wave itself is named a "wavefront".

Similar to waves in water, light also propagates in one direction with associated wavefronts. All of these wavefronts are at a distance of one wavelength apart.
Allochromatic light has an infinite amount of wavefronts, all at different distances depending on the wavelengths.

For a basic understanding, it is best to single out one light wave.

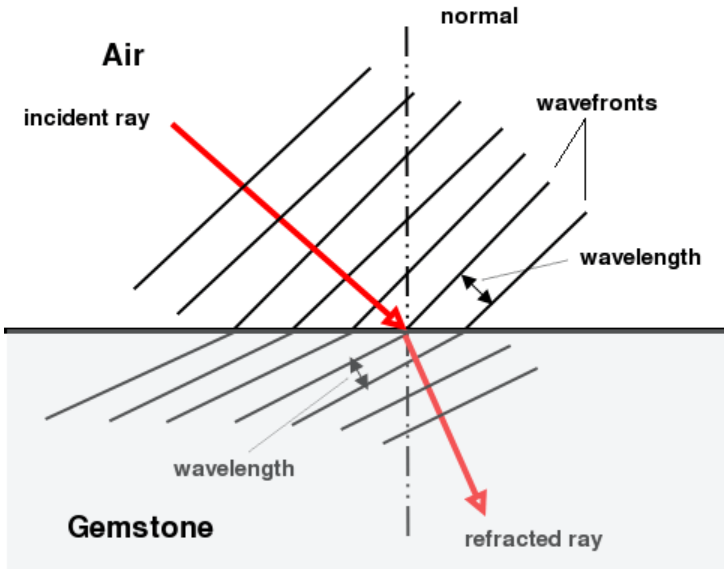


Figure 7.14.3*: Bending of wavefronts*

When light travels through air, it travels at a speed of approx. 300.000 km/second (actually, that is the speed in a vacuum). As it encounters an optically denser medium, light will be slowed down. This means the wavelength must shorten as well.
Thus the wavefronts of a particular light wave are closer together inside the denser medium (here, a gemstone) than they are in air. In order for the wavefront to stay intact, the wavefront must bend at the boundary between air and the gemstone (as illustrated on the left).

In the illustration, notice that the wavelength inside the gemstone (the distance between 2 wavefronts) is shorter than the original distances in air. Because the propagation of a light wave is perpendicular to the wavefront, the light wave must bend as well.

We as gemologists tend to associate color with wavelength and a logical conclusion could be that when the wavelength inside the mineral changes, so must the color of the light wave. However, our eyes and brains are sensitive to the frequency of the light wave instead of the wavelength. As the frequency isn't changed, neither is the color.
Through a series of goniometric calculations, one can derive Snell's law from this.

Snell's Law:

$$\frac{sin\Theta 1}{sin\Theta 2} = \frac{n2}{n1} \tag{7.14.4}$$

Where n1 is the index of refraction in air and n2 the refraction index inside the gemstone, Θ1 is the angle of incidence and Θ2 is the angle of refraction.

As the index of refraction of air is 1, we could rewrite that as:

$$\frac{sin\Theta 1}{sin\Theta 2} = n \tag{7.14.5}$$

Or:

$$n = \frac{\sin(angle\ of\ incidence)}{\sin(angle\ of\ refraction)} \tag{7.14.6}$$

Related topics

- Refractometer
- Dispersion
- Total Internal Reflection
- Nature of light
- Math for gemologists

Sources

- Introduction to Optical Mineralogy *3rd edition (2003), Prof. W.D. Nesse*

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7.15: Double Refraction

Some gemstones have more than one refractive index (RI) because these stones belong to crystal systems (anisotropic) that have atomic structures that cause an incident ray of light to be resolved into two rays traveling at different velocities. This difference related to velocities is named "birefringence". When the two rays change their direction of travel (i.e. are refracted) and move in different directions this phenomenon is called "double refraction. The numerical difference between one RI value and the other RI value measured in any one case is called the "birefringence" for that test, and the difference between the highest possible RI and the lowest possible RI considering all possible directions is called the birefringence of the gemstone.

Refraction is when light changes direction as it passes through a surface. Refringence is when light changes **velocity** as it passes through a surface. Light passing through a surface at the normal may be slowed down without being refracted. Light passing through a surface at an inclination allows the slowing of that light to change the direction of travel, yielding refraction. Birefringent materials slow light to two different velocities (according to each of two mutually perpendicular vibration directions). When light travels into a zircon through the prism face of a crystal, the vibrations are sorted in two and each vibration travels at a different velocity. If the light enters at an oblique angle, each vibration changes direction and travels along paths that differ from the original path AND differ from each other. This is double refraction caused by the birefringence. If the light enters normal to the prism face, each vibration travels at a different velocity, but **no refraction** occurs. Both vibrations were incident at a perpendicular to the wavefront so the velocity change does not cause a direction change. In this direction, the light experiences **zero refraction** and maximum birefringence.

Basic

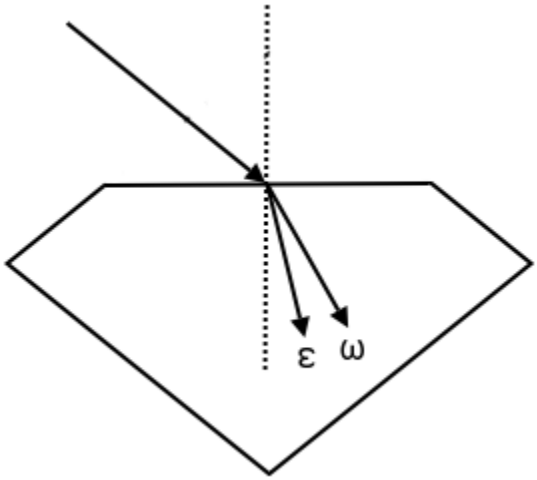


***Figure \({7{.}15{.}\eatSpaces{1} \endSpaces}|)**: Incident ray separated into an ordinary ray (ω) and an extra-ordinary ray (ε)*

When a ray of light enters the gemstone, the atomic structure allows only those rays vibrating in two specific directions to continue.
These two rays vibrate in planes that are mutually perpendicular and are therefore polarized. Both these rays travel at different velocities inside the gemstone and thus will refract at different angles when incident other than parallel to the normal.

The strength of birefringence (BI) varies with direction and we measure the maximum BI (Δ).
These maximum values differ from one gemstone to another. For instance:

- Strong BI - zircon (0.059)
- Medium BI - tourmaline (0.020)
- Low BI - quartz (0.009)

In uniaxial gemstones, one ray will vibrate in the direction perpendicular to the optic axis and will obey Snell's Law (one can calculate its angle of refraction). This ray is named the ordinary ray (usually indicated with ω). The other ray vibrates perpendicular to the vibration of the first ray and in a direction between perpendicular to and parallel to the optic axis (usually at some inclination) and so does not obey Snell's Law (i.e. the angle of refraction will vary according to the angle of vibration). That ray is named the extra-ordinary ray (indicated by ε).

The maximum RI difference between these two rays is named "birefringence", often indicated by the symbol "Δ" (Greek letter delta). This difference is largest when light enters the gemstone at an angle perpendicular to the optic axis. When light enters the gem at an angle parallel to the optic axis, the birefringence will be 0 (zero).
Although in gemology the term "birefringence" usually indicates the maximum difference between the ordinary and extra-ordinary rays (or the α and γ readings in biaxial stones), the term is also applied to any variation in refractive indices. Not just the maximum.

In faceted stones, a strong birefringence may result in visual doubling of facets, which is observed in a large number of zircons. Although the BI is at its maximum when viewed in the direction perpendicular to the optic axis, no doubling of facets will be seen in that direction due to superimposition.

When an anistropic stone is examined in the direction parallel to an optic axis, the stone will behave as an istropic gemstone. Therefore no doubling of facets will be seen in that direction either.

Gemstones belonging to the cubic crystal system and amorphous gems have only one RI and therefore do not show birefringence; all other gemstones do.
Uniaxial stones (those crystallizing in the trigonal, hexagonal and tetragonal systems) will show two readings and have one optic axis.
Biaxial gemstones (orthorhombic, monoclinic and triclinic systems) have two directions in which the incident light will react as if it were isotropic and therefore will have two optic axes.

Related Topics

- Refraction
- Refractometer
- Pleochroism

Sources

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- Richard H. Cartier - Journal of Gemmology, 2003, Vol. 28, no. 8, pp. 489-493
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7.16: Dispersion

Basic

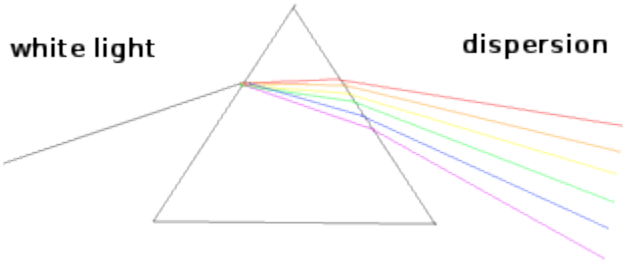


***Figure \({7{.}16{.}\eatSpaces{1} \endSpaces}\)**: Dispersion of white light in a prism*

Dispersion is the splitting up of white light into its individual wavelengths, what we see as colors. Dispersion occurs with transparent surfaces that are not parallel to each other, such as gemstone facets. Measurement of dispersion is done (in gemology) by calculating the difference of refraction indices for red light waves and violet light waves.

The source for red light travels at a wavelength of 686.7nm (named the Fraunhofer B-line) and at 430.8nm for violet light (the Fraunhofer G-line). The interval between red and violet gives the dispersion value of a gemstone.

All the individual wavelengths have their own refractive index numbers. Red light has a lower refraction index than violet light, thus the violet part of white light will bend more. These values are different for all gemstones, dependent upon the stone's optical density (how fast light can travel inside the gemstone). All transparent gemstones will show dispersion, but the dispersion colors may be masked by the body color of the gemstone. In Diamonds, the color dispersion of white light causes the spectacular "fire" in well-cut brilliant cuts that possess good white color. This "fire" is an interaction between color dispersion and total internal reflection.

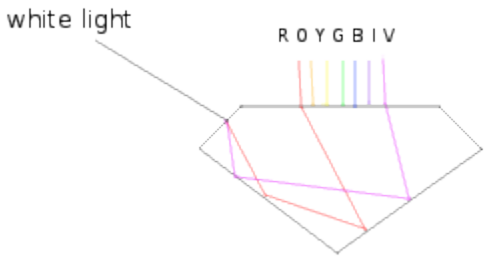


***Figure** 7.16.2: "Fire" in Diamond as the result of dispersion and total internal reflection*

The refraction index of Diamond (measured with n_D - or the Fraunhofer D-line) gives a refraction index of 2.417. The value for red light (n_B) in a Diamond is measured at 2.407 and for violet light (n_G) it is measured at 2.451. The interval between the B and the G lines is 2.407 - 2.451 = 0.044. Thus, the dispersion value of Diamond is 0.044.

This example shows that decreasing (shorter) wavelengths have increasing indices of refraction. This is known under the term *Normal dispersion of the refractive indices*.

Advanced

Measurement of dispersion is usually carried out using a table spectrometer. Through the minimum deviation method, very

accurate refraction indices can be obtained with this apparatus (more accurate than with the refractometer). This type of instrument can be obtained for around USD 1500.00, and takes some skill to operate.

An easier way to measure dispersion would be to use narrow bandpass interference filters on a refractometer. However, most refractometers are calibrated to take measurements on the sodium D-line, and the B and G lines may be hard to see for most humans.

Scientists usually measure dispersion between the C and the F lines, giving considerably different values. The values of these lines lay closer to what our eyes can distinguish, so measurements on the C and F lines may be valuable after interpolation to obtain the B and G line values.

Experimentation with narrow bandpass interference filters with wavelengths of 656nm (n_C) and 486nm (n_F) may give good results. One will, however, need to create a graph with calibration plates for the particular refractometer to correct the errors.

Dispersion of Some Common Gem Minerals

Gem Mineral	Dispersion
Anatase	0.213
Angelsite	0.044
Aquamarine	0.014
Benitoite	0.046
Beryl	0.014
Beryllonite	0.010
Boracite	0.024
Brazilianite	0.014
Brookite	0.131
Cassiterite	0.071
Celestite	0.014
Cerussite	0.055
Chrysoberyl	0.015
Corundum	0.018
Danburite	0.017
Datolite	0.016
Diamond	0.044
Dioptase	0.036
Epidote	0.019
Euclase	0.016
Feldspar, Orthoclase	0.012
Fluorite	0.007
Garnet, Andradite	0.057
Garnet, Almandite	0.027
Garnet, Grossularite	0.027
Garnet, Pyrope	0.022

Garnet, Rhodolite	0.026
Garnet, Spessartite	0.027
Goshenite	0.014
Hackmanite	0.018
Hambergite	0.015
Herderite	0.017
Idocrase	0.019
Iolite	0.017
Kornerupine	0.018
Kyanite	0.020
Moissanite	0.104
Peridot	0.020
Phenakite	0.005
Pollucite	0.012
Powellite	0.058
Quartz	0.013
Rhodizite	0.018
Rutile	0.280
Scapolite	0.017
Scheelite	0.038
Sillimanite	0.015
Smithsonite	0.037
Sphalerite	0.156
Sphene	0.051
Spinel	0.020
Spodumene	0.017
Staurolite	0.023
Tantalite	0.146
Topaz	0.014
Tourmaline	0.017
Vanadinite	0.202
Wulfenite	0.203
Zincite	0.127
Zircon	0.039

Related topics

- Refraction
- Fraunhofer

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7.17: Diffraction

Basic

In gemology, diffraction is the bending of light waves around an obstacle or sharp edge, either by transmission of light or reflection.

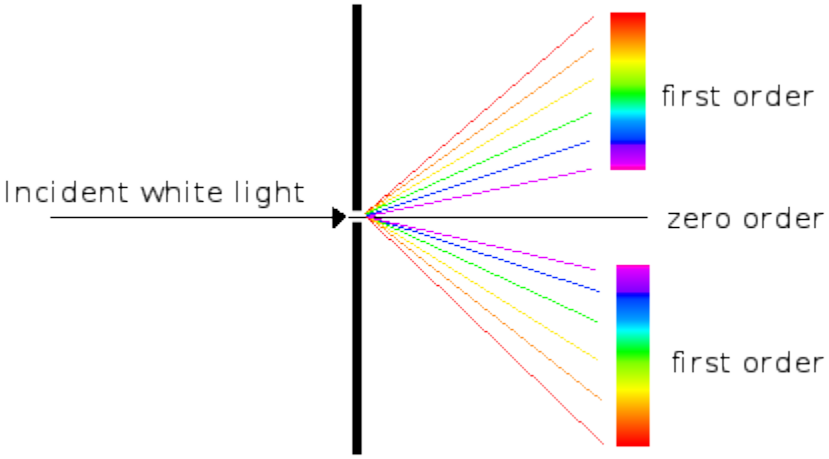


Figure 7.17.1*: Simplified diagram of diffraction of white light on a single slit*

Colin Winter compares diffraction to water coming from a hose. It will travel in one direction. If you hold your thumb partly over the opening, the water will be dispersed in different directions.
Diffraction is the dispersion of white light into its spectral colors (red, orange, yellow, green, blue, indigo and violet).

When dispersion happens with a prism, the violet part of the spectrum is bent the most, but in diffraction, it is the red light that gets thrown the furthest. This happens because the longer the wavelength, the more the waves will diffract.
As the diffraction occurs in radiant waves, you will see a repetition of spectra along the center of the zero order spectrum(where little to no dispersion occurs).
The first order spectra(on both sides of the zero order) are the ones most clear, so it is a first-order spectrum that is used in diffraction grating spectroscopes.

Diffraction grating material is made up of thousands of small grooves (or rulings) that run parallel over the transparent material, acting as slits.
This causes diffraction to occur on all those grooves. Due to interference, the different colors combine. The final result is seen as a series of spectra of white light after transmission through the grating material.

In opal, the spaces between silica spheres cause diffraction by reflection and is partly responsible for the famous opalescence of precious opal.

Related topics

- Dispersion
- Interference
- Spectroscope

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7.18: Interference

As explained in nature of light, light travels in transversal waves.

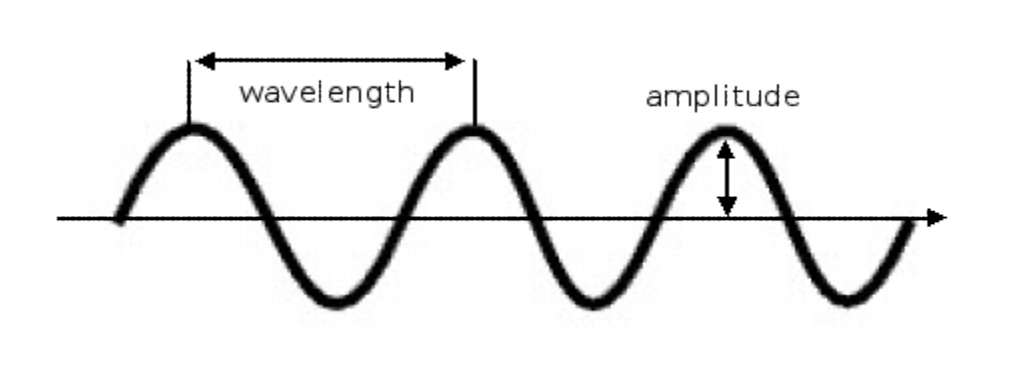


Figure 7.18.1*: Light wave*

The peaks of the waves are called *crests*, the valleys are named *troughs*.

The amplitude defines the intensity of the color, the wavelength is the distance between two *crests* (expressed in nanometers (nm)).

When white light hits the surface of a transparent material, like a gemstone, part of the light is reflected while another part is refracted inside the gemstone. The refracted ray will eventually reach another boundary and the same process repeats itself.

The part of the light that was refracted in the first run will be partially reflected and leave the gemstone.
Eventually, these two parts (both the original reflected and refracted/reflected waves) will travel alongside in air again after leaving the stone and try to join (or combine) again.

This can best be explained by a thin film (such as oil) laying on the street (Fig.2).

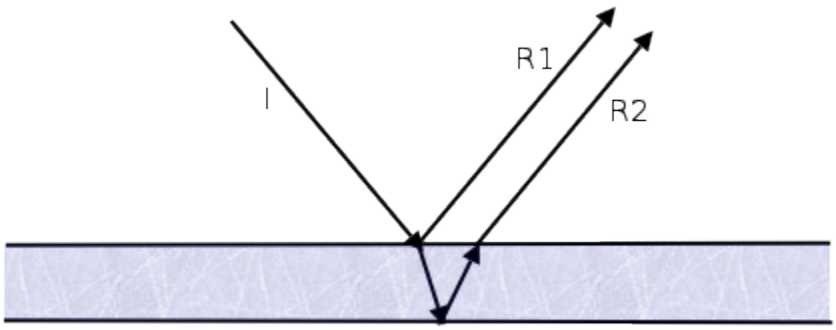


Figure 7.18.2*: Thin film*

The incident light (I) reaches the oil and part of it gets reflected (R1) while another part gets refracted inside the oil. The refracted part then reaches the boundary of oil/street and gets reflected out of the oil (R2).
Both R1 and R2 travel parallel to each other and try to combine.

When R1 and R2 travel with the crests and troughs next to one and other, the two rays will *constructively interfere* with one and other, creating a more intense color, creating a play of color as seen in oil slick or bath bubbles.

When one ray lags behind the other at a wavelength that is a half, they will *destructively interfere* and cancel each other out so no

color will be seen.

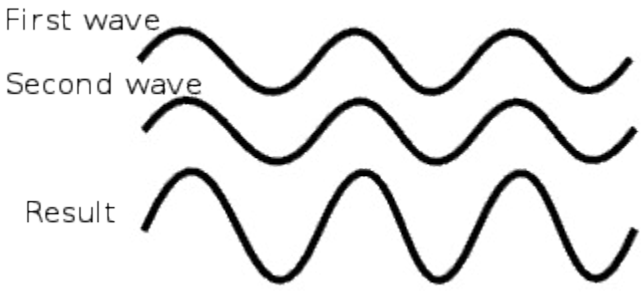


Figure 7.18.3*: Waves in phase*

Here the two waves travel with their crests and troughs as synchronized wavelengths and they will reinforce each other (Fig.3).
As seen in the picture, the result will be a doubling in amplitude, creating a more intense wave. This is what causes the play of colors due to interference.

A doubling of amplitude means a quadrupling of the intensity of the wavelength, meaning that the color will be more intense. Wavelengths with low amplitude will make them appear duller or even black.

Note that the wavelength doesn't change.

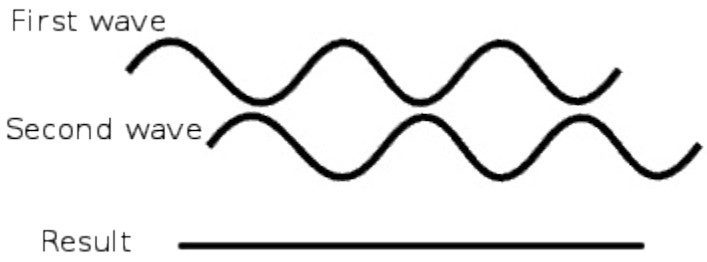


Figure 7.18.4*: Waves out of phase*

In Fig.4, you see that one ray is lagging behind the other at half a wavelength. The crests of the one are at the same position as the troughs of the other. This is what we call *retardation*.
Retardation is the lagging of one ray behind the other.

In this case, the retardation is by one-half a wavelength, so they cancel each other out. The result is a wave that has no amplitude.

A wave with no amplitude is black.

When two rays lag behind each other at a full wavelength (or 2 or 3, etc.), we say that they are *in phase* and will *constructively interfere*, and so play of color will be observed.
If the retardation is a half a wavelength (or 1.5 etc), the waves will cancel each other out by *destructive interference*, and we then say the two rays are *out of phase*.

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7.19: Luminescence

Luminescence is the phenomenon that shows itself as a "glowing" of a gemstone. This is caused by absorption of energy and the releasing of surplus of this energy in small amounts.
The sources of energy are usually ultraviolet light, X-ray light, and even visible light. When energy comes from light, it is referred to as *photoluminescence*.

In gemology we are usually only concerned with the following types of luminescence:

- Fluorescence
- Phosphorescence
- Triboluminescence
- Tenebrescence (not technically a luminescence)
- Cathodoluminescence
- Thermoluminescence

The causes of luminescence are varied but are mostly due to impurities ("activators") or due to defects in the crystal lattice. In general, the presence of iron inside the gemstone kills or suppresses luminescence.

Fluorescence

Basic

Fluorescence is the emission of visible light by a gemstone when exposed to electromagnetic radiation of higher energy (shorter wavelength). When the gemstone is exposed to such radiation, electrons are elevated to a higher energy state, thus absorbing the energy. If the return to the ground state includes energy emission that corresponds to visible light, fluorescence is produced. Thus fluorescence is the emission of visible light when exposed to any radiation of higher energy. In gemology, the most common excitation energy for fluorescence is ultraviolet light.

Although some people understand this as a speeding up of light, this is incorrect. (Neither is it caused by the slowing down of light inside the gemstone because the slowing down results in shorter wavelengths, not longer ones. See refraction).

All rays of light carry a specific amount of energy. Light with a shorter wavelength has higher energy. This energy is expressed in eV (electron Volts). For instance, red light has energy of around 1.8eV while violet light has 3.1eV of energy.
When the loss of energy of UV light (with an energy of -- let's say -- 4eV) is 2.2eV, this results in 1.8eV, hence red light (4 - 2.2 = 1.8).
There is no actual "loss" of the energy, it is converted to other kinds of energy like heat.

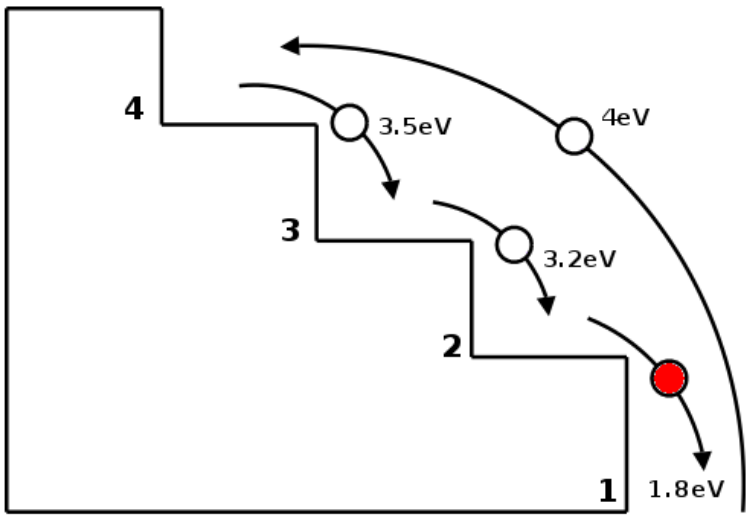


Figure 7.19.1*: Simplified diagram showing cause of fluorescence*

This might best be explained with a ball that gets tossed upward onto a staircase.
If you threw the ball up onto the stairs, that motion would require energy (the energy coming from your arm). Let's say that the ball now carries 4eV of energy and this is just enough to get it from the ground state (1) to the 3rd board (4). As it then drops from level 4 to level 3, it would lose part of that energy (in this example 0.5eV). So the ball still has 3.5eV of energy. It will then drop to level 2, losing an additional 0.3eV of energy. After this, it will drop down to the ground again while carrying only 1.8eV of energy. When it reaches the ground state again, the ball loses all its surplus energy.

Now imagine the ball being an electron and the source of energy (formerly your arm) is ultraviolet light. As the electron gets 4eV of energy from the UV light source we can't see it as light (we can only see it as it reaches 3.1eV, which corresponds to violet light), consequently, it will lose more and more energy as it drops down level by level. When it reaches level 2, it has an energy of 1.8eV which corresponds with red light, so the electron will now emit red light.

As long as energy is fed to the electrons (in the form of UV light), this process is continuous and this process only takes a fraction of a second (a femtosecond or 10^{-15} seconds). How much energy that is required for a gemstone to fluoresce varies from stone to stone, for Ruby that is 3eV and explains why the best Rubies appear to glow like a hot coil in daylight.
Not all gemstones will show this phenomenon and those gemstones lose the extra energy in another way.

The fluorescence lifespan is relative to the UV light source, meaning that if you turn off the light source the fluorescence is gone.

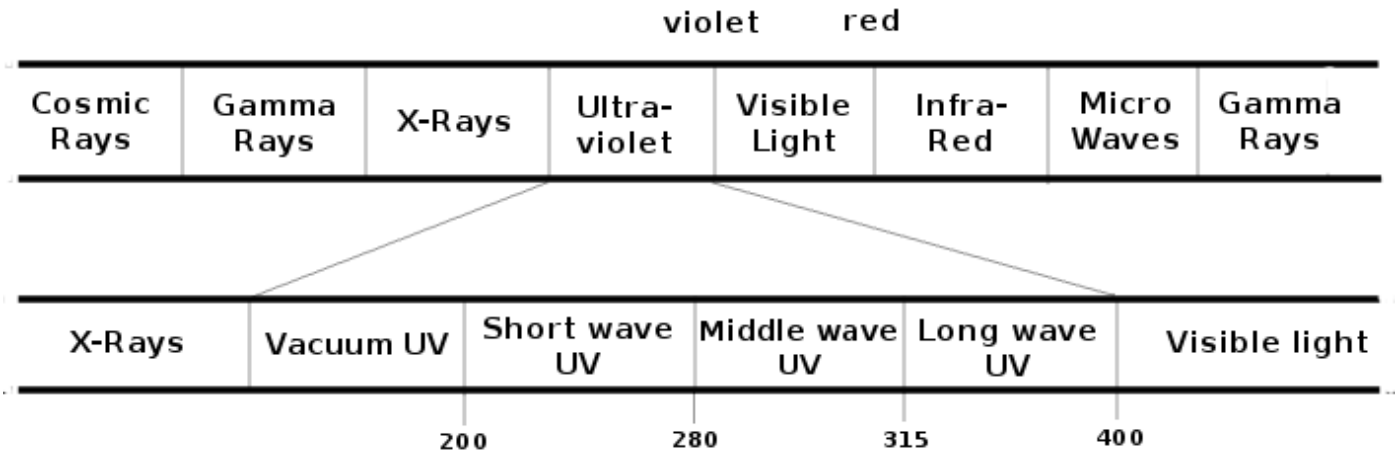


Figure 7.19.2*: The electromagnetic spectrum and the place of ultraviolet light*

For day-to-day use, we use two different types of UV light:

- Shortwave ultraviolet light, or S-UV (with a wavelength of about 254nm)
- Longwave ultraviolet light, or L-UV (with a wavelength of about 366nm)

Warning: When using UV light, make sure to protect your eyes as they are damaging! This is particularly true for S-UV.

Some colors that might be seen in a UV viewing cabinet:

Table 7.19.1**: Fluorescence**

L-UV	S-UV
Ivory	Synth. white Spinel
Opal	
Ruby	
Red Spinel	
Synth. Emerald	
Nat. blue Sapphire	
Alexandrite	
Kunzite	
Lapis lazuli	
Sodalite	
Zircon	Zircon
Topaz	
Apatite	
Diamond	Synth. white Spinel
Moonstone	
Fluorite	

Gemological Application of Laser Pointers

Recently, laser pointers and UV LEDs have become commercially available in a UV wavelength range in about 20 nm increments. A discussion has started as to the gemological application of these devices, specifically a laser pointer emitting a 405 nm beam. These pointers have dramatically dropped in price and are currently available for less than $40 US. One must always use extreme caution when using laser pointers as they can cause serious eye damage. Protective goggles are available. Goggles are inexpensive and mandatory for use with laser pointer experimentation. Of course, one can also make observations using the laser pointer within their old UV cabinets for safety.
Observations are as follows:

Figure 7.19.2: Observations Reported Using a 4	
Gemstone	**Reaction**
Cubic Zirconia (Colorless)	Inert
Diamond (D through O-P color)	Blue mild to strong
Emerald (natural)	Red Glow
Emerald (natural)	Inert
Jadeite (natural, untreated)	Inert
Ruby (natural and synthetic)	Intense Red Glow
Sapphire(Blue natural and synthetic)	Usually inert to faint diffused
Sapphire(Blue natural)	Red: moderate to intense
Sapphire(Violet and Purple natural)	Red: moderate to intense

Advanced

Crossed filters technique

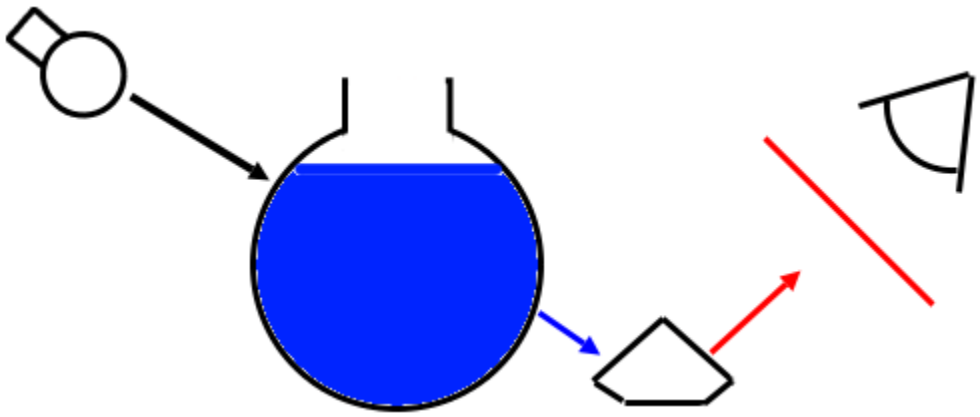


Figure 7.19.3*: Copper Sulphate solution in a flask and a red filter*

The "crossed filters" technique should not be confused with "crossed polars" or "crossed polaroids" as they have to do with polarization, not luminescence.
A flask is filled with hydrous copper sulfate and white light is being passed through the solution. The exiting light will be blue. During the illumination of the gemstone with this blue light, a red filter is placed between the eye of the observer and the stone. When the stone appears red, when viewed through the red filter, this is clear proof that the stone is fluorescent in daylight.
The activator in the gem which causes this is the presence of Chromium (Cr) in the crystal lattice and this effect is predominantly seen in Ruby, Alexandrite, Emerald, red Spinel and pink Topaz. It should be noted that Iron (Fe) can greatly diminish or completely eliminate this fluorescence effect. As synthetic materials usually carry more Cr and little to none Fe, this glowing of red light is more intense than in their natural counterparts (in general).

The hassle of carrying hydrous copper sulfate is luckily eliminated by the invention of blue LED pocket (or keychain) torches that may be purchased for just a few USD at your local hardware shop. One could use a sheet of red selenium glass as the red filter, or even your Chelsea Color Filter. Other sheets like plastics could also serve as crossed filters.
With a sheet of blue material in front of one's light source, one can mimic the copper sulfate solution and/or the LED torch.

Using the same light source in conjunction with a spectroscope, one can then easily distinguish between Ruby and red Spinel.

Table 7.19.3: Relationship between wavelength				
			<-------- wavelength --------	
wavelength	800nm	700nm	600nm	
energy	1.55eV	1.77eV	2.07eV	
			--------- energy --------->	

Phosphorescence

Basic

Phosphorescence is similar to fluorescence but differs in the "lifetime" the glow fades. In Phosphorescent materials, the glow, or better the "after-glow", can range from a fraction of a second to several hours (although the latter is usually not observed in minerals).

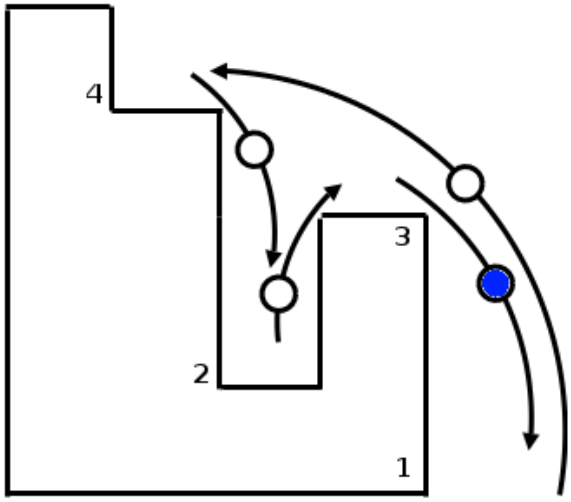


***Figure \(\PageIndex{4}\)**: The "trap" diagram*

When an electron gets enough energy from an energy source as UV light, the electron will jump from its ground state (1) to a higher energy level (4). The electron will fall into a gap (2) rather than to the energy level just below 4 (3).
As a result, the electron will be "trapped" in the gap and needs extra energy (also provided by the UV light source) to jump out. While the UV energy source feeds the electrons, fluorescence is seen, yet when the source is shut down the electrons stay in the trap until other energy is provided to free them.
The energy required to get the electron out of the trap comes from white light (with thermal energy, or heat at room temperature). As white light doesn't carry as much energy as UV light, the release of the electron goes at a slower rate, thus creating an after-glow. During this period the phenomenon is named phosphorescence.

One can look at the freeing of the electron as "bleaching".

Tenebrescence (see below) can be explained by this as well, yet the energy required to free the electron is higher. You can visualize it as a deeper gap if you will.

Triboluminescence

Triboluminescence is caused by pressure, friction or mechanical stress in any way applied to a gemstone.
Opposed to fluorescence, phosphorescence, and tenebrescence, triboluminescence is not caused by light, hence it is not to be

named photoluminescence. Instead, it is the result of electric charges, therefore *electroluminescence*.
This effect is usually seen in diamond cutting. When the diamond is sawn or cleaved, electric charges break free from the stone and immediately recombine, showing a red or blue glow.

Tenebrescence

Although tenebrescence is not technically a luminescence, it shares some common characteristics with phosphorescence. Technically, tenebrescence is an unstable color caused by low energy artificial irradiation (forming a color center) from the UV light source.
The main difference between luminescence and tenebrescence is that a fluorescent or phosphorescent stone will glow in the dark, while a tenebrescent gem needs light to show its color. More technically: a tenebrescent stone needs an external energy source (light) to show its color, while luminescence is a release of "stored" energy.

In 1896, a vibrant pink variety of sodalite was discovered in Greenland by L.C. Boergstroem. The pink color of this unusual sodalite faded to colorless when exposed to light. The sodalite will return to its original pink color when it is placed in the dark for an extended period of time, or when exposed to short wave ultraviolet light. This transformation can be repeated endlessly. Tenebrescence is defined by minerals that are able to make this color transformation; minerals that display the ability to change color in this fashion are termed tenebrescent. Tenebrescence is the property that some minerals and phosphors show of darkening in response to radiation of one wavelength and then reversibly bleaching on exposure to a different wavelength. Very few minerals exhibit this phenomenon, also known as reversible photochromism, a word that applies to sunglasses that change color density on exposure to sunlight.

Sodalite that shows this behavior has been given the variety name hackmanite. The pink color in this mineral is unstable because it fades very quickly when exposed to light.

Other examples of minerals that lose or gain color when exposed to light are:

Tugtupite -- some light colored varieties of tugtupite, especially pale pink material -- will intensify in color as a result of exposure to shortwave UV or even under strong sunlight (but not artificial light).
Spodumene will achieve a darkening of color to pink or purple with exposure to high-energy radiation.
Chameleon diamonds are olive colored diamonds that temporarily change color after having been stored in darkness or when gently heated. Chameleon diamonds display hues and tones from light to dark olive (the stable color phase) through light to medium yellow (the unstable color phase). After one to two days in darkness, exposure to light changes the color of a chameleon diamond from the unstable yellow color back to the stable olive. This is observed as an infinitely repeatable process.
Amethysts from Globe, Arizona and some sherry-colored topaz are reported to lose their color in the sun, but in this case, the loss of color is irreversible.
White barite from the Gaskin Mine in Pope County, Illinois will change to blue, and yellow barite will change to gray-green when exposed to ultraviolet light.

The pink color of hackmanite may be restored in two ways. One way is by leaving the specimen in the dark for a few hours to several weeks, and the other way is by exposure to ultraviolet. Short-wave ultraviolet is the most efficient for this purpose. The speed with which this is accomplished and the depth of the color achieved varies from specimen to specimen.


Hackmanite4.jpg

Figure 7.19.5 *: Tenebrescence*

In some specimens, long exposure to ultraviolet light is required to produce a faint degree of pink color. In other specimens, exposure to short-wave ultraviolet will almost instantly produce a pink color. In the latter specimens, additional exposure to ultraviolet light for several minutes to a few hours will produce a deep pink to raspberry-red color in which a weak blue component is evident. This can be seen in some specimens from Mont Saint-Hilaire and Khibina. If the specimen is then put in the dark, the

deep red color will exhibit phosphorescence, also known as "afterglow". Visible light (wavelengths between 480-720 nanometers) will quickly reverse the process and render the specimen colorless once again.

This photochromic effect can be repeated indefinitely, although any heating of the mineral destroys tenebrescence forever.

Research indicates that F-Centers are at least partially the cause for the tenebrescence in hackmanite. The term F-Centers is derived from the German word Farbe, meaning color. An F-center is a defect in an ionic lattice that occurs when an anion leaves as a neutral species, leaving a cavity and a negative charge behind. This negative charge is then shared by the neighboring positive charges in the lattice. F-Centers are responsible for coloring a variety of minerals, including fluorite and barite. (Nassau, 1983) In hackmanite, it is proposed that some of the negatively charged chlorine atoms are missing. A negative electric charge is required at such vacancies to provide charge balance, and any free electrons in the vicinity become drawn to such vacancies and are trapped there. Such a trapped electron is the typical basis of an F-Center. It appears that this center in hackmanite absorbs green, yellow, and orange light and varying amounts of blue. When the hackmanite is seen in white light, red and some blue are returned to the eye, giving the hackmanite colors.

A mineral may produce a certain color that depends on different but fixed arrangements of electrons (Nassau, 1983). Hackmanite absorbs the energy from the ultraviolet radiation and many electrons get stuck in a new, high-energy position in atoms (F-centers), causing the mineral to have a different color when the lights of the UV light source are turned on. But when we turn the room lights on, the new color fades. White light (the visible spectrum) also energizes electrons, just not as much as ultraviolet light. The white light has the necessary energy to "unstick" the electrons from the F-Centers, thus returning the mineral to colorless.

A fairly recent find (2005) in Badakhshan, Afghanistan is tenebrescent scapolite. This colorless to silvery material is unearthed near the hackmanite deposits and shows an aquamarine color after exposure to SW UV light. The intensity of this color (blue) depends on the length of time it has been exposed to the UV lighting.
Exposure to a UVP UVG4 SW UV lamp for 15 minutes triggered an almost Santa Maria aquamarine blue color that faded gradually during the following 10-15 minutes in natural daylight.

Cathodoluminescence

Cathodoluminescence is another type of luminescence which is of some importance in gemology. It is the emission of energy, which may have a characteristic spectrum by materials which are in an electron beam. The most familiar form of cathodoluminescence (often abbreviated CL) is the light emitted by the screen of a video monitor. If you look at the red green and blue dots you are seeing characteristic spectra of three different phosphors. In a monochrome monitor which may come in almost any color including white, it is a single phosphor being excited in the electron beam.

CL is excited in special CL chambers and also in electron microscopes which already have the electron beam handy. It has long been used by mineralogists. The electron beam is higher in energy than short wave UV or X rays all of which can be used to excite more conventional fluorescence. Many synthetic diamonds show characteristic growth lines under cathodoluminescent examination. It is an advanced or research gemology technique.

Thermoluminescence

Fluorite can store energy from UV radiation and when the mineral is heated, it will release part that energy through luminescence.

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- *Gem-A Diploma Syllabus* (1987)
- *Crossed Filters revisited* - D.B.Hoover and B. Williams, The Journal of Gemmology, July/October 2005
- *A Status Report on Gemstones From Afghanistan* - Gems & Gemology, Winter 1985, Gary Bowersox
- *Update on Hackmanite* - Gems & Gemology, Winter 1989, Gem News
- *The Physics & Chemistry of Color* - Kurt Nassau, 1983
- *An Introduction to Rock Forming Minerals* - Deer, Howie & Zussman 1966
- *Hackmanite* - Brochure supplied by SoCalNevada, on Hackmanite from the Kola Peninsula, Russia
- *The origins of color in minerals* - Kurt Nassau, American Mineralogist Volume 63, pages 219-229, 1978 [1]

External links

- Jablonski diagram
- Basic Concepts in Fluorescence
- www.minershop.com/html/tenebrescense.html
- luminousminerals.com/greenland/tenebrescence.shtml
- Classification of Hackmanite w/ localitites

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7.20: External Links

- Total Internal Reflection
- Degrees, minutes and seconds
- Electromagnetic waves and circular dichroism: an animated tutorial
- Video lecture by Professor Lewin at MIT about refraction, TIR, dispersion and color - High speed - Low speed (Realmedia format)
- Reflection and Refraction Java simulation
- Refraction of Light
- Light Refraction
- Practical application for measuring gemstone dispersion on the refractometer
- Jablonski diagram
- Basic Concepts in Fluorescence
- www.minershop.com/html/tenebrescense.html
- luminousminerals.com/greenland/tenebrescence.shtml
- Classification of Hackmanite w/ localitites
- Anomalous Double Refraction video (Barbra Voltaire, hosted by Google Video)

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8: HARDNESS

8.1: Hardness

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8.1: Hardness

Hardness of a gemstone is one of the components that defines the durability of gemstones. (Other components are toughness, brittleness and stability - resistance to heat and/or chemicals.) In gemology, we define hardness as the ability to withstand abrasion by other materials.

Basic

Mohs hardness scale

Mohs scale of relative hardness	
1.	Talc
2	Gypsum
3.	Calcite
4.	Fluorspar
5.	Apatite
6.	Orthoclase feldspar
7.	Quartz
8.	Topaz
9.	Corundum
10.	Diamond

In the early 19th century, Friedrich Mohs developed a scale of relative hardness for minerals. He composed a list of 10 minerals with known hardness and organized them on an ascending scale, with talc at the lower end and diamond at the highest end.
This scale indicates that corundum can scratch topaz (and all others lower on the list) but not diamond.

It should be noted that this is not a linear scale. The difference in actual hardness between diamond and corundum is 10 times higher than the difference between talc and corundum [Read, 2005]. Thus it is a comparative hardness scale, with the hardness of one mineral relative to another mineral on the list.

As can be seen in the list, quartz has a hardness of 7 on Mohs scale. Quartz is one of the most abundant minerals on Earth and is even in dust particles that constantly float through the air. This is why minerals with a hardness less than 7 will abrade relatively rapidly with normal wear.

Of course, all minerals could be put on the scale, but that would create an almost endless list.

The method of testing the hardness of gemstones is by the use of hardness pencils.

Hardness pencils

Hardness pencils are pencils with a tip made of one of the 10 minerals on Mohs scale.
These pencils are used to try and scratch a stone and observe if the pencils can scratch the gem. Since this is a destructive method (it leaves a scratch), this test is mostly used on pieces of rough or on an inconspicuous place on the gemstone. Not many gemologists use this test as there are better ways to determine a gemstone's identity.

When one does feel the need to apply this test, one must do it in a logical manner.
The gemstone is tested with a pencil of low hardness (starting at 4 or lower) to try to put a tiny scratch on the stone without applying pressure. If no scratch is observed, one repeats this process with a pencil of higher hardness (in this case 5) and so on until one arrives at the pencil that is able to put a tiny scratch on the stone.
For instance, if one could not scratch the mineral with pencil no.7 but it would leave a scratch with pencil no.8, the hardness of the mineral must be between 7 and 8 on Mohs scale.

Directional hardness

Due to various causes, some minerals are harder in one direction than in another direction. Kyanite has a hardness of 5 in the basal plane direction, while it has a hardness of 7 in the prismatic directions. This phenomenon of varying hardness in different directions is named "directional hardness".
Diamond also has a profound directional hardness. Diamond is softer in the octahedral planes and harder in the cubic planes

(and even softer in the dodecahedral planes). This property helps the diamond cutter, because diamond dust (which is orientated in a random fashion) will always have part of the dust aligned in its hardest direction, so it can easily be used to saw and polish in the octahedral direction of a to-be-cut diamond.

Directional hardness is also named "differential hardness".

References

- Gemmology 3rd edition (2005) - Peter Read

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9: SPECIFIC GRAVITY

9.1: Specific Gravity

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9.1: Specific Gravity

The specific gravity (SG) of gemstones is a constant widely used in gemological property charts. Although not every gemologist enjoys doing an SG test, it is still a property which can be very useful when other general tests fail.
The method of determination uses a hydrostatic balance.

Basic

Specific gravity (also known as "relative density") is the ratio between the weight of a stone in the air and the weight of an equal volume in water. By convention, the temperature of the water is 4° C and at standard atmosphere because the density of water is greatest under these conditions. Room temperature conditions are adequate for gemological purposes, as the small difference in density of the water will have little effect on the readings (measured to the second decimal).

Since specific gravity is relative to the weight of an object in air and its weight in water, it is a ratio and isn't expressed in units (such as kg/m^3). For instance, the SG of Diamond = 3.52 (whereas the density of Diamond = 3.52 g/cm^3).

In gemology, specific gravity is, usually, determined through an apparatus based on Archimedes' Principle.
Archimedes' Principle (or the Law of Buoyancy) states that: the upward force on an immersed object is equal to the weight of the displaced fluid.
This may sound complicated but it is a fairly simple, yet brilliant, law.

Consider two balls of equal weight but of different specific gravity, for instance, a 10-gram gold ball and a 10-gram silver ball. The gold ball has an sg of 19.3, while silver has an sg of 10.5.
Because gold has an sg that is almost twice as much as silver, you can imagine that the 10-gram gold ball will be smaller than the 10-gram silver ball. In other words, the gold ball will have a smaller volume than the silver ball.
When you hang both balls in water (immersed), then the silver ball will displace much more water than the golden ball due to its higher volume.

Water has an sg of 1, so the weight of a cubic centimeter of water is 1 gram (actually 0.0098 Newton, but grams used for simplicity). Through some simple math, we can calculate the volume of the balls. The volume of the gold ball is 0.52 cubic centimeter and the volume of the silver ball is 0.95 cubic centimeter (volume is mass divided by density).
From this, we can conclude that the silver ball will displace 0.95 cubic centimeter of water, which weighs 0.95 gram. The golden ball will displace 0.52 grams of water (because 1 cubic centimeter of water weighs 1 gram).

Now back to Archimedes' Principle: the upward force on an immersed object is equal to the weight of the displaced fluid (the fluid being water in this case). The silver ball displaces a higher weight of water, so it will experience a larger upward force than the golden ball and will rise higher in the water when immersed.

A common mistake is to drop the object in the water in a way that it will sink to the bottom. It can not work in that case as it is then no longer "immersed".

Density

Density is different from specific gravity in that it is the mass of an object divided by its volume, expressed in kg/m^3 by SI (Le Système International d'Unités - The International System of Units) standards. In gemology, g/cm^3 is used. Other weighing systems are still widely in use (mostly in the USA and the UK), but the metric system of the SI is slowly finding its way there as well.

Mass and weight

Mass is the amount of material in an object and is a physical property of that object (like a gemstone), expressed in kg (kilogram) by SI standards.

Weight is the gravitational force ($9.8\ m/s^2$) on that object and is expressed in N (newton). Weight is not a physical property as it

may change in different situations. A stone would weigh less on Earth's moon than on Earth, but its mass would remain the same.

As can be concluded, we should use "mass" instead of "weight" when being scientifically correct, but in daily use mass and weight are interchangeable.

The carat (ct) is an accepted unit of mass (or weight, if you please).

Measurement of specific gravity

The method of measuring SG is with a hydrostatic balance.
First, the stone is weighed in air and then weighed when fully immersed in water. After this, the weights are inserted into a simple formula.

$$SG = \frac{weight\ of\ stone\ in\ air}{weight\ of\ stone\ in\ air\ -\ weight\ of\ stone\ in\ water} \tag{9.1.1}$$

A demonstration can be seen in this video.

Video presentation

YouTube Video

This interactive element is not available in this format. Visit the link or scan the

View this YouTube Video online

Video 9.1.1: Video showing the method of determining

Specific Gravity of Some Common Gem Minerals

Table 9.1.1: *Specific Gravity of Common Gems*

Gem Mineral	
Agate	
Alexandrite	
Allanite	
Almandine (Garnet)	
Amazonite (Feldspar)	
Amber	
Amblygonite	
Amethyst	
Ametrine	
Anatase	
Andalusite	

Andesine (Feldspar)	
Andradite (Garnet)	
Apatite	
Apophyllite	
Aquamarine (Beryl)	
Aventurine	
Axinite	
Azurite	
Barite	
Bastnäsite	
Benitoite	
Beryl	
Beryllonite	
Bixbite (Beryl)	
Brazilianite	
Bronzite	
Calcite	
Carnelian	
Cassiterite	
Celestite	
Cerussite	
Chalcedony	
Chrome Diopside	
Chrysoberyl	
Chrysocolla	
Chrysoprase	
Citrine	
Clinozoisite	
Colemanite	
Coral	
Crocoite	
Cubic Zirconia	
Cuprite	
Danburite	
Datolite	
Demantoid (Andradite)	
Diamond	
Diopside	

Dioptase	
Dolomite	
Dumortierite	
Ekanite	
Emerald (Beryl)	
Enstatite	
Epidote	
Euclase	
Fayalite (Olivine)	
Fibrolite (sillimanite)	
Fire Opal	
Fluorite	
Gahnite	
Gahnospinel	
Glass (man-made)	
Goshenite (Beryl)	
Grossular (Garnet)	
Hackmanite	
Hambergite	
Hauyne	
Heliodor (Beryl)	
Hematite	
Hemimorphite	
Hessonite (Garnet)	
Hiddenite (Spodumene)	
Howlite	
Hydrogrossular (Garnet)	
Hypersthene	
Idocrase	
Iolite	
Ivory	
Jadeite	
Jasper (Quartz)	
Kornerupine	
Kunzite (Spodumene)	
Kyanite	
Labradorite (Feldspar)	
Lapis Lazuli	

Lazulite	
Leucite	
Magnesite	
Malachite	
Maw-Sit-Sit	
Microline (Feldspar)	
Moissanite	
Moldavite	
Moonstone (Feldspar)	
Morganite (Beryl)	
Natrolite	
Nephrite	
Obsidian	
Oligoclase (Feldspar)	
Onyx	
Opal	
Orthoclase (Feldspar)	
Pearl (cultured)	
Pearl (natural)	
Peridot (Olivine)	
Petalite	
Phenakite	
Prasiolite (Quartz)	
Prehnite	
Proustite	
Purpurite	
Pyrope (Garnet) 3.70	
Quartz	
Rhodizite	
Rhodochrosite	
Rhodolite (Garnet)	
Rhodonite	
Ruby (Corundum)	
Rutile	
Sanidine (Feldspar)	
Sapphire (Corundum)	
Sapphirine	
Scapolite	

Scheelite	
Serpentine	
Sillimanite	
Silver	
Sinhalite	
Smithsonite	
Sodalite	
Spessartine (Garnet)	
Sphalerite	
Sphene	
Spinel	
Spodumene	
Staurolite	
Strontium Titanate	
Taaffeite	
Tantalite	
Tanzanite (Zoisite)	
Thomsonite	
Thulite (Zoisite)	
Tiger eye (Quartz)	
Topaz (colorless)	
Topaz (yellow)	
Tourmaline	
Tremolite	
Tsavorite (Garnet)	
Tugtupite	
Turquoise	
Ulexite	
Uvarovite (Garnet)	
Vanadinite	
Variscite	
Vesuvianite	
Vivianite	
Willemite	
Wulfenite	
Zincite	
Zircon, (colorless, blue)	
Zircon, (green)	

Zoisite	

Related topics

- Hydrostatic Balance

External Links

- Specific Gravity Video (Barbra Voltaire, Hosted by Google Video)

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10: BASIC MATH FOR GEMOLOGY

10.1: Math

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10.1: Math

Although the study of gemology requires no formal prior training, a high school diploma would make it easier to understand basic math. Knowledge of trigonometry especially might serve you well.

Below are some basic calculations that you may want to understand.

Cross-multiplication

Some people have trouble with cross multiplications, while it is fairly easy if you keep a simple equation in mind.

$$5 = \frac{10}{2} \tag{10.1.1}$$

which is the same as

$$\frac{5}{1} = \frac{10}{2} \tag{10.1.2}$$

because 5 divided by 1 = 5.

Let's say you want to bring the 10 to the left of the equation. Obviously 10 = 5 times 2, so you cross-multiply.

$$\frac{5}{1} \swarrow \frac{10}{2} \tag{10.1.3}$$

we multiply 10 with 1 to get it to the left side and:

$$\frac{5}{1} \searrow \frac{10}{2} \tag{10.1.4}$$

we multiply 5 with 2, so we get: $10 * 1 = 5 * 2$ or $10 = 5 * 2$

This would probably make more sense in the following equation:

$$\frac{6}{3} = \frac{4}{2} \tag{10.1.5}$$

If you would cross-multiply, you would get $4 * 3 = 12$ and $6 * 2 = 12$, so $12 = 12$.

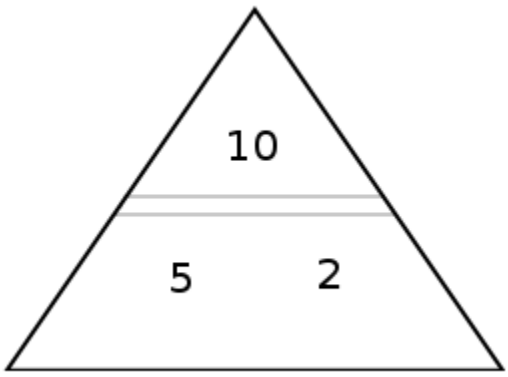


Figure 10.1.1

We can do it easier with the aid of a simple diagram. In Figure 10.1.1, you see a triangle with the equation $10 = 5 * 2$ (the "$*$" is left out). The double horizontal bars serve as the "$=$" sign OR as the "/" (division) sign.

With this simple diagram in mind, you can solve most simple cross multiplications.

How to read the triangle:

- You start at one number and then go the next and then to the 3rd
- You work your way up first, then down

Examples:

- Say you start at 2
- Then you go up and see the "=" sign. Now you have "$2 =$"
- Then you move up further, you meet the 10, so you have "$2 = 10$"
- You can't go any further up, so you must go down. You meet the double lines again, but they can't be a second "=", so they serve as a division. Now you have "$2 = 10/$"
- You go down further and see the 5, that makes "$2 = 10/5$"

It works the same when you start with 5.

Now let's start with 10:

- You start with 10, so "10"
- You can't go further up, so you must go down. You encounter the double lines. As they are the first time you see them, they are the "=", now you have "$10 =$"
- Then you meet the 5 (or the 2 depending if you go clockwise or anti-clockwise), making "$10 = 5$"
- You can't go further down, so must go sideways. You see the 2, making the odd-looking "$10 = 52$". This is actually good math style but is confusing, so we need to place an "$*$" between them. The result is "$10 = 5x2$", which any prep school kid would agree on.

This is of course not much fun because all the answers are given. But this simple knowledge is basic when you want to solve an equation such as:

$$2.417 = \frac{300}{x} \tag{10.1.6}$$

Simply replace "$10 = 5 * 2$" with the numbers and the unknown "x" of the new equation in the triangle. (Hint: the "x" takes the place of the "2")

Give it a try and see if you can calculate the speed of light inside a diamond with the above equation (the 300 is short for 300,000 km/s, which is the speed of light in a vacuum).

If all else fails, keep $5 = \frac{10}{2}$ in mind and substitute the numbers for the unknowns in the equation you need to solve.

Sine, cosine, and tangent

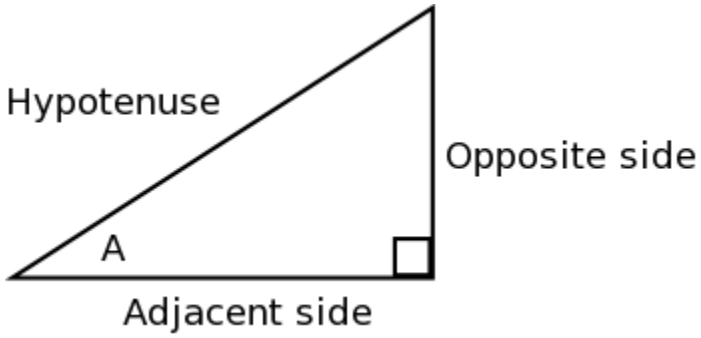


Figure 10.1.2

The sine, cosine, and tangent are used to calculate angles.

In Figure 10.1.2, the 3 sides of a right triangle (seen from corner A) are labeled Adjacent side, Opposite side and Hypotenuse. The hypotenuse is always the slanted (and longest) side in a right triangle.

The opposite and adjacent sides are relative to corner A. If A would be at the other acute corner, they would be reversed.

Sine

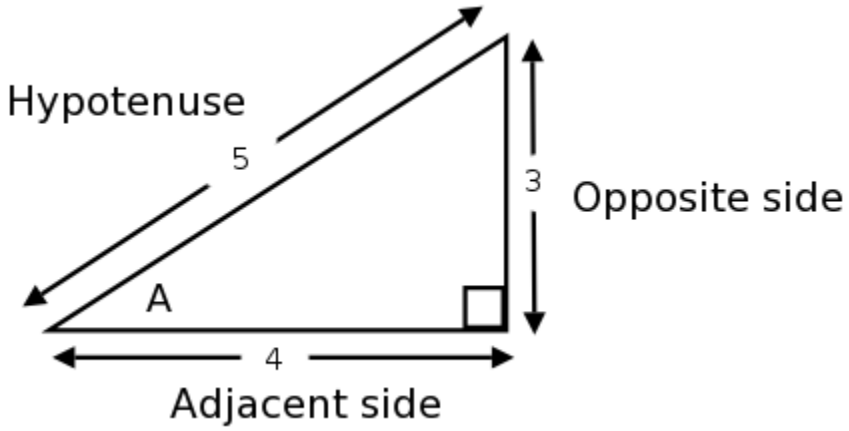


Figure 10.1.3

Sine is usually abbreviated as *sin*.

You can calculate the sine of a corner in a right triangle by dividing the opposite side by the hypotenuse. For this you need to know two values:

1. the value of the opposite side
2. the value of the hypotenuse.

In Figure 10.1.3 those values are 3 and 5, the sine of A or better sin(A) is 3/5 = 0.6

$$\sin = \frac{opposite\ side}{hypotenuse} = \frac{3}{5} = 0.6 \tag{10.1.7}$$

Now that you have the sine of corner A, you would like to know the angle of that corner.
The angle of corner A is the "inverse sine" (denoted as $\sin^{-1}$ or arcsin) of the sine and is done by complex calculation. Luckily we have electronic calculators to do the dirty work for us:

- type in 0.6
- press the "INV" button
- press the "sin" button

This should give you approximately 36.87, so the angle of corner A is 36.87°

$$\arcsin(\sin A) = \arcsin(0.6) = 36.87 \tag{10.1.8}$$

When you know the angle a corner makes, lets say 30°, you can calculate the sine as follows:

- type in 30
- press sin

That should give you 0.5

Practical use

If you know the angles of incidence and refraction in a gemstone, you can calculate the refraction index of that gemstone. Or do other fun things like:

$$index\ of\ refraction = \frac{sin\ i}{sin\ r} \tag{10.1.9}$$

Diamond has a refraction index of 2.417, so if the angle of incidence is 30°, the angle of refraction can be calculated as:

$$\sin r = \frac{\sin i}{n} = \frac{\sin 30}{2.417} = \frac{0.5}{2.417} = 0.207 \tag{10.1.10}$$

so using the inverse sine:

$$\arcsin(\sin r) = \arcsin(0.207) = 11.947 \Rightarrow angle\ of\ refraction = 11.947^{\circ} \tag{10.1.11}$$

It's not all rocket science. Read the page on refraction if you don't know what is meant by angle of incidence and angle of refraction.

Calculating the critical angle

Calculating the critical angle of a gemstone is pretty easy although the formula might scare you.

$$critical\ angle = \arcsin\left(\frac{1}{n}\right) \tag{10.1.12}$$

Where n is the refractive index of the gemstone.

The actual formula is $\arcsin(n_2/n_1)$, but as we gemologists usually are only concerned with the critical angle between air and the gem, n2 = 1.

The calculation of this formula is easy, we'll use quartz with n = 1.54 as an example.
When you use a windows calculator, make sure you are in scientific mode. Then press the following buttons:

- 1
- /
- 1.54
- =

Then check the "inv" checkbox and press the "sin" button. That should give you an approximate value of 40.493, so the critical angle for quartz is 40.5° (rounded down to one decimal).

Cosine

The cosine of a corner in a right triangle is similar to the sine, yet now calculation is done with the division of the adjacent side by the hypotenuse. The cosine is abbreviated as "cos"

In Figure 10.1.3, that would be 4 divided by 5 = 0.8

$$\cos = \frac{adjacent\ side}{hypotenuse} = \frac{4}{5} = 0.8 \tag{10.1.13}$$

Again as with the sine, the inverse of the cosine is the arccos or $\cos^{-1}$:

- type in 0.8
- press INV
- press cos

This should give you 36.87 as well, so the angle remains 36.87° (as expected).

$$\arccos(\cos A) = \arccos(0.8) = 36.87 \tag{10.1.14}$$

Tangent

The 3rd way to calculate an angle is through the tangent (or shortened to "tan"). The tangent of an angle is opposite side divided by adjacent side.

$$\tan = \frac{opposite\ side}{adjacent\ side} \tag{10.1.15}$$

For Figure 10.1.3, that will be 3/4 = 0.75
Calculation of the angle is as above, but using the arctan or $\tan^{-1}$:

- type in 0.75
- press INV
- press tan

This should give you 36.87, so through this method of calculation the angle of corner A is again 36.87°.

$$\arctan(\tan A) = \arctan(0.75) = 36.87 \tag{10.1.16}$$

A simple bridge to remember which sides you need in the calculations is the bridge SOH-CAH-TOA.

- SOH = Sine-Opposite-Hypotenuse
- CAH = Cosine-Adjacent-Hypotenuse
- TOA = Tangent-Opposite-Adjacent

Degrees, minutes and seconds

When we think of degrees we usually associate it with temperature and we consider minutes and seconds as attributes of time. However, in trigonometry, they are used to describe angles of a circle and we refer to them as the *radian* values.

A full circle has 360 degrees, or 360°.
Every degree can be divided into 60 minutes (like in a clock) instead of the 10 decimal subdivisions.
Minutes are notated with a ', as in 26'.
The individual minutes are further divided into 60 seconds and they are described with ", as in 23".

This may look odd at first, but it's not very hard to understand.

If you have an angle of 24°26'23" (24 degrees, 26 minutes and 23 seconds), this means that the decimal value is:

- 24°
- 26 divided by 60 or 26/60 = 0.433°
- 23/(60 * 60) or 23/3600 = 0.0063°

This totals as 24 + 0.433 + 0.0063 = 24.439° in the decimal value (which is the decimal value of the critical angle of diamond).

When you want to calculate the *radian* value of 24.439°, you do the following:

- the 24 stays 24 (because that doesn't change)
- you try to find how many times 0.439 times 60 fits in the degree by: 60 times 0.439 = 26.34, so that is 26 full minutes (0.34 left over)
- you calculate the seconds through 60 times 0.34 = 20.4 (or 20 full seconds because we don't count lower than seconds).

This gives 24°26'20" (24° + 26' + 20") instead of the 24°26'23". The 3-second difference is caused by the rounding down to 3 decimals in the prior calculation. In gemology, we usually don't even mention the seconds, so it will be rounded down to ≈ 24°26'.

Even though you may not need this knowledge often, it is important that you at least know of its existence as you may get confused when reading articles. Sometimes values are given in decimal degrees, at other times in radian values.

External links

- Introduction to mathematics
- Sine definition with Java demo
- Cosine definition with Java demo
- Tangent definition with Java demo

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11: EQUIPMENT USED TO IDENTIFY GEMSTONES

11.01: Introduction

11.02: 10x Loupe

11.03: Spectroscope

11.04: Refractometer

11.05: Polariscope

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11.07: Immersion Cell

11.08: Color Filters

11.09: Microscope

11.10: Hydrostatic Balance

11.11: Heavy Liquids

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11.01: Introduction

First and foremost, use your eyes and your brain!

Gemology is a science of elimination. Based on the observation of the various properties of a gem, the possibilities of what it could be are removed until you are left with only one possibility: the correct identification.

Some gems are easily identified with a few simple tests, like rubbing a pearl across your teeth to see if it feels rough or smooth. But before doing so, you have already subconsciously eliminated all of the other gemstones other than pearl based on the visual observations that you have made: color, shape, luster, etc. Of course, the "tooth test" won't tell you if it's cultured or not, or in the case of colored pearls, if they have been irradiated or dyed.

Most gemstones are considerably less easy to identify. In order to isolate the various properties of a gem, gemology requires some specialized equipment.

A word of caution:

> Simply buying the equipment needed for gemology is not enough. One needs formal training from an expert to learn how to apply techniques so one doesn't embrace bad habits that are hard to get rid of.
>
> It is strongly recommended that you take practical training from one of the institutes outlined in "becoming a gemologist".

Learning the math is not the same as being able to correctly apply it; that's elementary, my dear.

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11.02: 10x Loupe

After the eye and the brain, the 10x Loupe (or "hand lens") is the instrument most used by gemologists.
It is used to inspect the interior and exterior of a gemstone, and is the primary instrument used for clarity grading of Diamonds.
A good 10x Loupe can be bought for under USD 50.00 and a gemologist should carry it with her/him at all times.

It is recommended that you buy a loupe with a matte black casing around the lenses to prevent reflections. Golden and chromed casings may look nice, but they can interfere with colors.

About lenses

Lenses used in optics are usually made of crown and flint glass.
Crown glass has a refractive index between 1.5 and 1.6 and is low dispersive, while flint glass may have higher refraction indices and is highly dispersive. Both types work complementary and are widely used in gemological loupes.

Lenses are cut in different shapes (convex, concave and combinations) following Coddington Shape factors for best form. This is to eliminate spherical and chromatic aberrations, which would distort the image.
The best forms, however, do not eliminate the aberrations completely, therefore several lenses (two or three) are cemented together for optimum performance. These are named compound lenses. The "doublet" loupes have 2 lenses while the "triplet" loupes have 3 lenses of various shapes cemented together.

Magnification

The 10x means that the loupe will magnify an image 10 times, so a $1mm^2$ square will appear to be $1cm^2$.

Gemological loupes come in different magnifications (from 3x up to 30x) and with different fields of view. For everyday use, a 10x triplet lens with a large field of view (25.4mm) is your best choice. The higher magnification ones usually have a smaller working distance (the distance between the loupe and the gemstone).
The standard 10x loupe has a working distance of about 2.5 cm, while a 20x loupe will have a 1.25 cm working distance.

You can measure what the working distance for you is by the following formula:

$$Working\ distance = \frac{least\ distance\ of\ focus}{10} \tag{11.2.1}$$

The "least distance of focus" is different for every person. You can measure it by holding a ruler next to your eye (pointing away from you and the zero position lined up with your eye), then place the nail of your thumb (from the other hand) close in front of your eye. Close your other eye.
You will notice that the nail is out of focus. Now slowly slide your thumb along the ruler until the nail of your thumb is in sharp focus. Read the value of the ruler where the focus is full and that is your personal "least distance of focus". For me, the original author of this section, that was at 17cm, so my working distance is 1.7 cm.

Although one might expect that a 20x loupe will give a better view of the item being examined, that is only the case for experienced users and only then after having first examined the object with a 10x lens. The reason for this is that the higher the magnification, the lesser your field of view and the lesser the margin of focus.
With a 10x lens you will have an average working distance of about 2.5 cm with some margin below and before. Although the focus outside your working distance is not optimal, you can still see the area reasonably well.
For a 20x loupe, those margins are all half and it will be extremely difficult to see "the big picture", causing you to miss an inclusion in a stone completely. Therefore use the 20x hand lens only in addition to the 10x loupe for a closer inspection.

Another good reason for using a 10x loupe is that it is the standard in clarity grading for Diamonds.

Chromatic aberration

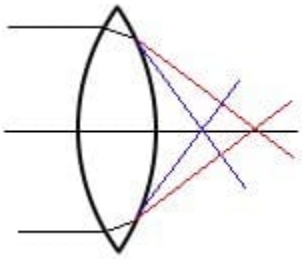


Figure 11.2.1

Chromatic aberration refers to color fringing of the image due to dispersion inside the glass lens. The outer edges of the lens refract the most and hence more dispersion will occur from light rays at those points.

To overcome this, two lenses (one bi-concave and one bi-convex) of different dispersive powers (crown and flint glass) are placed side by side.
Loupes that are corrected for chromatic aberration are named "achromatic".

Spherical aberration

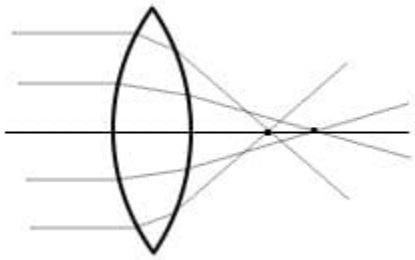


Figure 11.2.2

Lenses also suffer from spherical distortion, also caused by differences in refraction on the outer edges from the lens and the rays which travel through the center. This results in a hazy and out of focus view.

Correction can be achieved by adding a lens with different curves (like a plano-convex lens) in the loupe. A spherical corrected loupe is called "aplanic".
When the loupe is both aplanic and achromatic, we name it "apochromatic".

Doublet loupe

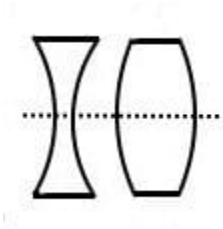


Figure 11.2.3**:** *Two lenses "doublet"*

Doublet loupes consist of two lenses (hence the name "doublet"). The lenses are either corrected for chromatic aberration (achromatic) or spherical aberration (aplanic). In the image to the left two lenses (one bi-concave and one bi-convex) are placed close after each other and cemented together, which will correct the chromatic aberration (achromatic).
When two lenses are used where each lens has a different curvature (concavo-convex or plano-convex), it is an aplanic or othoscopic loupe.

These loupes are relatively inexpensive (under USD 10.00) and should best not be used in gemology for reasons outlined earlier.

Triplet loupe

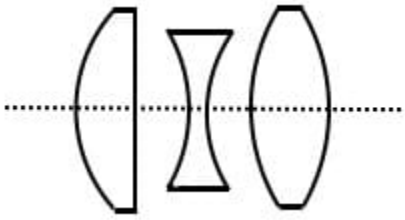


Figure 11.2.4***:*** *Three lenses "triplet"*

The triplet loupe consists of three lenses cemented close together. In the image above, you see three lenses that make up a triplet loupe (other configurations are possible). From left to right they are:

- A plano-convex lens to eliminate the spherical aberration
- A bi-concave lens
- A bi-convex lens

The latter two overcome the chromatic aberration. All three together they form an apochromatic loupe. This is the loupe you will need as a gemologist.

Testing of the loupe

You can test your loupe for chromatic aberration by looking at a white light source through your loupe. If the image remains white (also on the outer edge) it will be achromatic.
Spherical aberration can be tested on mm squared drawing paper. The squares should remain square in the total view of your loupe.

Proper use of the 10x loupe

In order to be successful working with the hand lens, one must practice with it first.
Unfold the loupe and hold the lens casing between index finger and thumb. Place the lens just before your eye (or just before your spectacles), letting the back of your thumb rest against the side of your nose to keep the loupe steady.
The three remaining fingers should be parallel with or just below your index finger.

With your other hand, hold an object and bring it in front of the lens. To steady the object, let the thumb of the hand that holds the object rest against the middle finger of the hand that holds the loupe. Manipulate the object in a wiggly motion while keeping the thumb and middle finger in contact. Practice this with several objects until you get a feel for the loupe.
From there on you can exercise with gemstones held in tweezers to explore external and internal features in gemstones. When you find yourself on hands and knees searching for stones that popped out of the tweezers, don't be alarmed. All gemologists have red knees.

To keep your eyes from strain, try to keep both eyes open, the unused eye staring blank.

Related topics

- Microscope

Sources

- Gemmology 3rd edition (2005) - Peter Read
- *Gem-A* Foundation notes
- *Gem Identification Made Easy* 3th edition (2006) - A. C. Bonanno, Antoinette Matlins

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11.03: Spectroscope

The spectroscope is a tool for examining which parts of white light are absorbed by a gemstone (as well as by other materials). Materials can absorb parts of the electromagnetic spectrum, and when the absorbed parts fall within the visible range, that absorbed part will influence the color of the material.
When a gemstone is observed with a spectroscope, the absorbed parts show as dark lines and/or bands in the spectroscope image.

There are two types of spectroscopes used in gemology:

1. Diffraction grating spectroscopes (based on diffraction)
2. Prism spectroscopes (based on dispersion)

Basic

Absorption

Color, as perceived by the human eye, consists of the 7 colors of the rainbow: Red, Orange, Yellow, Green, Blue, Indigo and Violet. All these colors travel at different speeds and have their own wavelengths. When all the above colors combine, we see it as white light.

When white light reaches a substance, part of the light components may be absorbed by the substance. The other light components (residue) form the color of that substance. For instance, if a gemstone absorbs all the colors of the rainbow except red, only the red part of the original white light will be visible, and the gemstone will, therefore, be red.
When viewed through a spectroscope, the absorbed parts of light by that gemstone will disappear from the spectrum image and only red will be visible in the prism of the spectroscope.
Likewise, if all colors except red and blue are absorbed by a gemstone, the residual colors (red and blue) will give rise to a purple gemstone.

The pictures below give a crude example of both above-mentioned situations.

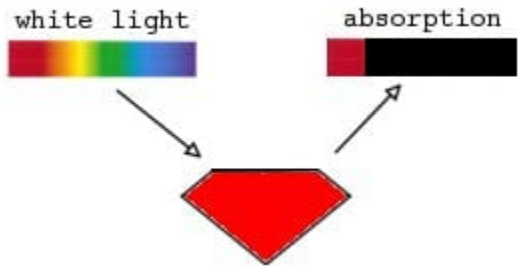


Figure 11.3.1***:*** *Absorption of all wavelengths except red*

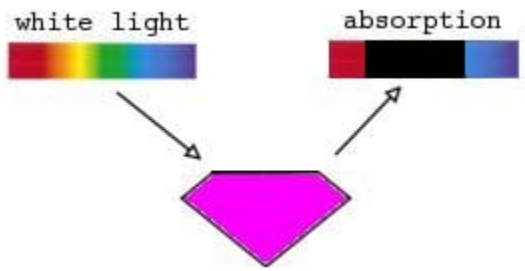


Figure 11.3.2***:*** *Absorption of all wavelengths except red and blue*

Of course, in real life, the spectrum images are much more sophisticated, with small lines and bands indicating specific absorption parts of white light.
The energy from the absorbed colors (or better, "wavelengths") is transformed inside the gemstone into other types of energy, mostly heat.

One should consider color as a form of energy traveling at a specific wavelength.

Types of spectroscopes

In gemology, we make use of two different types of spectroscopes, each with its own characteristics.

1. Diffraction grating spectroscope

The diffraction grating spectroscope is based on the principle of diffraction. Maybe the best-known brand is OPL, which is produced in the UK by Colin Winter.
Light enters through a narrow slit and is then diffracted by a thin film of diffraction grating material. This produces a linear spectrum image with a generally larger view of the red part than a prism spectroscope.
These spectroscopes do not have a built-in scale.



Figure 11.3.3***:*** *Diffraction grating spectrum*

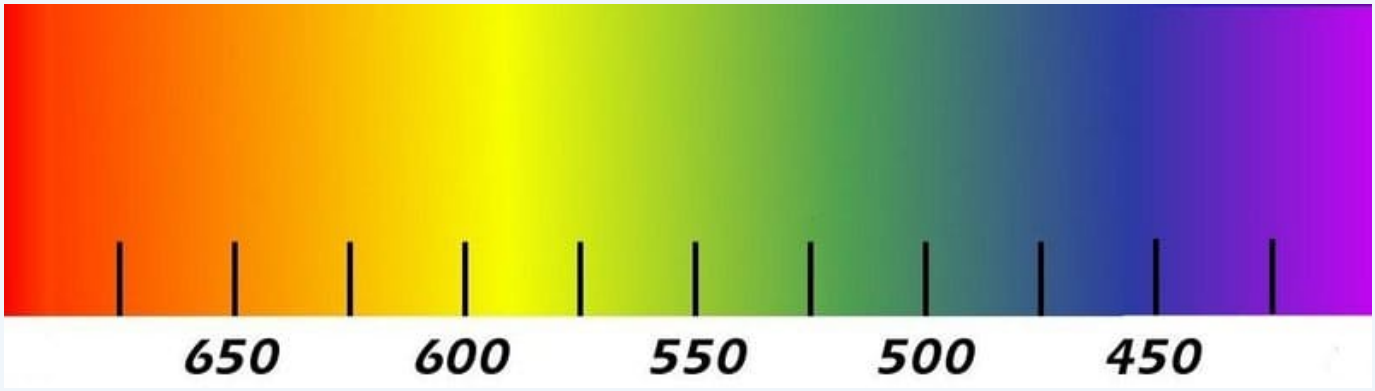


Figure 11.3.4***:*** *Diffraction grating spectrum with scale in nm*

2. Prism spectroscope

The prism spectroscope is based on dispersion. The light enters through a narrow slit (some models allow you to adjust the width

of the slit) and is then dispersed through a series of prisms. Some models have an attachment with a built-in scale. These models are generally more expensive than their diffraction type cousins.
Because prism spectroscopes are based on dispersion, the blue area of the spectrum is more spread out and the red parts are more condensed than the diffraction grating types.



Figure 11.3.6***:****Prism spectrum*



Figure 7***:*** *Prism spectrum with scale in nm*

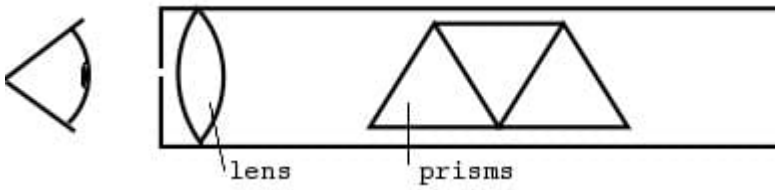


Figure **\(\PageIndex{8}\):** *Inside the prism spectroscop*

Use of the spectroscope

Using the spectroscope poses many problems for those who are not familiar with the instrument. Therefore, before attempting to determine the absorption spectra of gems, it is best to hold the spectroscope against some different sources of illumination, such as a fluorescent light bulb, a computer monitor, etc. This will show you very clear absorption bands in most cases.

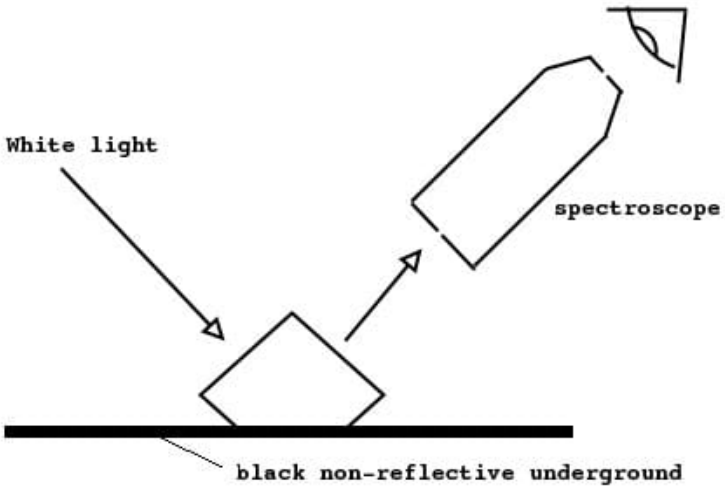


Figure 11.3.9***:*** *Use of the spectroscope with reflected light*

Proper use of the spectroscope and lighting is vital when wanting to see good spectra of gemstones.
The most widely used technique is to make use of reflected light. Light enters the pavilion of a gemstone at a 45° angle and the spectroscope should be placed at the same angle on the other side.
The light will travel its longest possible path in this way, picking up the most color.

To prevent the background on which the stone lays from causing false readings, one should use a black non-reflective underground, such as a small piece of black velvet.

Another technique is to position the gemstone and the light source (penlight) in one hand in such a way that the light source illuminates the gem from behind, thus viewing the gemstone in transmitted light.

There are nice spectroscope stands (some with built-in illumination) on the market, but gaining some experience eliminates the need for them.
For the new user, it is recommended to start with a gemstone that produces a clear absorption spectrum, such as synthetic ruby.

Related topics

- Fraunhofer
- Dispersion
- Diffraction

Sources

- *A Students' Guide to Spectroscopy* (2003) - Colin Winter FGA, DGA

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11.04: Refractometer

The refractometer is one of the most important tools in a gemological laboratory. It indicates (not measures) the refraction index of a gemstone, which often gives vital clues to the identity of a gemstone.

Although one would expect a refractometer to measure the refraction of light inside a gemstone, this is not the case. Instead it is based on a unique optical phenomenon named *Total Internal Reflection* (or TIR).

For a better understanding of the refractometer, you first need to understand refraction.

Basic

Construction of a gemological refractometer

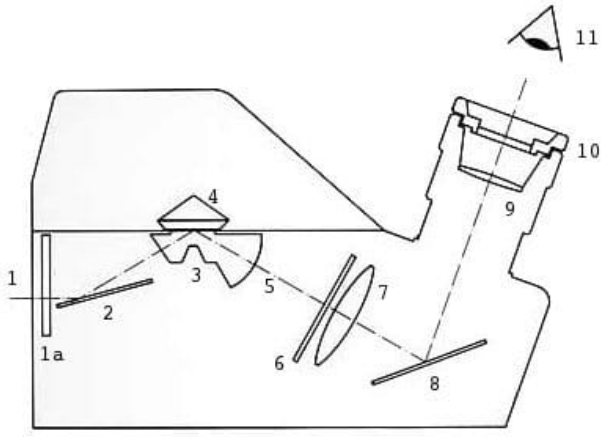


Figure 11.4.1***:*** *Cross section of a standard gemological refractometer (modified image from an Eickhorst SR 0.005 refractometer)*

Light (1) enters through the rear of the refractometer through an opening (1a) in (or before) which a yellow sodium filter can be placed. It then hits a mirror (2) which transmits the light to the center of the hemicylinder (3).
This hemicylinder is made of high refractive glass (usually N-LaSF by Schott with a refractive index of ~ 1.88 at n_D and a hardness of about 6.5 on Moh's scale).
At the boundary between the hemicylinder and the gemstone (4), the light will be partially refracted inside the stone and partially reflected in the hemicylinder (see below on Total Internal reflection). The reflected rays (5) will pass through a reading scale (6) and a lens (7) or a series of lenses, depending on the type of refractometer.
The reflected rays hit a mirror (8) which directs the light to the ocular (9) and then outside the refractometer to your eye (11).
The ocular (9) can slide in and out for better focus and is usually accompanied by a detachable polarizing filter (10).

As the hemicylinder has a relatively low hardness compared to most gemstones, care must be taken not to scratch it. That would ruin your refractometer, as optical contact between the gemstone and the cylinder would be impossible and would give you false readings.

Total Internal Reflection

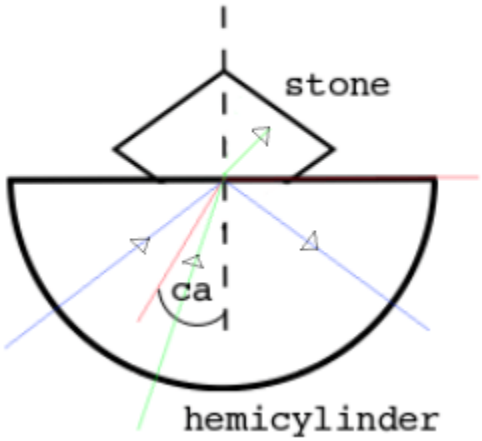


Figure 11.4.2***:*** *Inside the refractometer: Total Internal Reflection*

When light travels from an optically denser material (with higher index of refraction) to an optically rarer material (with lower index of refraction), all light that reaches the boundary of the two materials will be either reflected inside the denser material or refracted into the rarer material, depending on the angle of incidence of the light.

For every two media in contact in which light is traveling from the denser to the rarer medium, the dividing line where either the ray of light is totally reflected or refracted is fixed and can be calculated. This dividing line is named the *critical angle* (ca). On the left you find an image showing the critical angle as the red line.
When light reaches the boundary of the two materials at an angle larger than this critical angle (the blue line), the ray of light will be totally reflected back into the denser material. Light reaching the boundary at an angle smaller than the critical angle will be refracted out of the denser medium (and a small amount will be reflected) into the rarer medium (the green line). All light traveling precisely on the critical angle will follow the path of the boundary between the two materials.

> Note
>
> In the example above, the light seems to come from 3 light sources, but the principle is the same when coming from a single point.

In a hemicylinder, the incident and exiting ray always reach the boundary at a 90-degree angle when directed to the center. Refraction doesn't occur when a light ray is at 90 degrees to the boundary. A hemicylinder is used so there will be no refraction of the light entering or leaving the denser material.

The standard gemological refractometer can make use of this phenomenon because the reflected rays of light will appear as a light area on the scale, whilst the refracted rays are not visible (and therefore appear black). The light/dark boundary shown on the scale of the refractometer is a visible representation of the critical angle.
The standard gemological refractometer thus measures the critical angle between the glass hemicylinder and the gemstone and plots that on a calibrated scale. This type of refractometer is hence better named a "critical angle refractometer".

Lighting

Proper lighting is one of the key features when using the refractometer.

Although one can get results using a white light source, the standard is monochromatic yellow light with a wavelength of about 589.3nm. This light source is historically used as it was easily produced by burning table salt in a candle (at a very low cost). All gemological refraction indices are based on the use of sodium light (or n_D). For more information, see Fraunhofer.

The use of different wavelengths can produce different readings. As the refractive indices of gemstones are measured with an accuracy of 0.001 decimal, sodium light should be used. All gemological tables of refractive indices are produced using this light unless otherwise stated.

White light may be used for single refractive gemstones or to obtain a first impression. One should look for the boundary between the green and the yellow of the allochromatic white light source.

However, for double refractive gemstones, one should then switch to a sodium light source, simply for the reason that the double refraction readings in white light may easily overlap and it would be impossible to get a correct reading. And of course the boundary between the lighter and darker areas is better defined, making the reading easier to take.

Always buy a refractometer with either a sodium filter or a sodium light source.

Contact liquids

Here things get a bit more complicated.

Contact liquids are used to create an optical contact between the hemicylinder and the gemstone. This is to prevent air from trapping between the facet of the stone and the hemicylinder, which would ruin the Total Internal Reflection effect.

As this contact liquid also has it's own refractive index, there will also be Total Internal Reflection between the hemicylinder and the liquid. It is important to ensure that the tiniest drop of liquid is used so the stone doesn't float on the liquid. Use just enough to create a "thin film". Donald Hoover added to this through personal communication that too much liquid will not only lift up the stone slightly, the reading may also be off slightly due to the refraction inside the liquid (the ray will deviate slightly). With a thin film, this is marginal and will have little to none effect on the reading.

The result is obviously two Total Internal Reflection readings, one from the hemicylinder-liquid and the other from the liquid-stone boundary (which will be, due to laws of refraction, the same as if no liquid were used). That is the reason you will also see a faint reading near the higher index of the scale on the refractometer, which is the reading of the liquid.

The refractive index of the liquid sets the limit of which stones can be tested on the refractometer. Usually, the liquid has a refractive index of 1.79, but some have a refractive index of 1.81. **You can not measure stones that have a RI higher than the liquid used.** Stones with a higher RI than the liquid will give you a "negative reading".

Liquids with higher RI are available, but they are so toxic that they are only used in specially equipped laboratories. They would, of course, also need a special hemicylinder which will be of higher RI than the liquid.

You should always shield your contact liquids from light (especially for the 1.81 type) and care should be taken not to let the liquids crystallize.

The chemical compositions of the liquids are:

- 1.79 - Saturated solution of sulfur and di-idiomethane
- 1.81 - Saturated solution of sulfur, di-idiomethane and tetraidioethylene

Always wash your hands after you make physical contact with the liquids -- not only for the smell.

Use of the Refractometer

Video 11.4.1***:*** *Video showing how to use a refractometer*

As with every instrument, success depends on proper usage.

First, you apply a very small drop of contact liquid on the center of the hemicylinder of the refractometer, after which you place the stone you want to investigate table down next to the hemicylinder. With your fingernail, slide the stone on the center of the hemicylinder. For an oval stone, place it lengthwise.

At this point, the contact liquid will suck under the facet and provide an optical contact between the stone and the hemicylinder. Do not apply any pressure to the stone by pushing it down on the cylinder as that would damage the hemicylinder. (Repairs are

very costly.) Close the lid of the refractometer to shield the stone from any surrounding light. Remove the polarizing filter if it hasn't been removed already.

Now, with the light source in place at the back, place your best eye (usually your right one) just before the ocular of the refractometer. You should position your eye so that you look at a straight angle to the ocular, to prevent a "parallax error". The best way to know your eye is in the right position is if you can see the whole scale (or most of it) without moving your eye.

Now find the dividing line between light and dark on the scale. (For gemstones cut en-cabochon, the technique is slightly different. See the "distant vision" method below.) If the scale seems blurry, you can slide the ocular in and out for better focus. Now you can start taking your readings (explained below).

When you are finished, gently slide the stone off the hemicylinder and remove the stone with your fingers if possible. It is important to keep the hemicylinder clean, so use a clean cloth or tissue to gently wipe any remaining contact liquid from the cylinder. Do this gently without any pressure, making a North-South motion.

As mentioned above, the hemicylinder is made of a relatively low hardness glass and can easily scratch. **So always make sure you keep abrasive materials and sharp objects (like tweezers) away from the hemicylinder.**

Look at the images below to see how to properly use the refractometer.

Click images to enlarge



Figure 11.4.3***:*** *Open liquid bottle and get small drop*



Figure 11.4.4***:*** *Carefully place on middle of hemicylinder*



Figure 11.4.5***:*** *L*

N.B: Some people find it hard to get a small drop of liquid directly from the bottle. A different technique is to place a series of small drops (usually 2 or 3) next to the hemicylinder and place the stone on the smallest drop, then slide the stone and liquid together onto the hemicylinder. Alternatively, one can lose excess liquid from the liquid rod by making a few drops next to the hemicylinder and then apply the remainder directly onto the refractometer's hemicylinder. Whichever method one prefers will work.

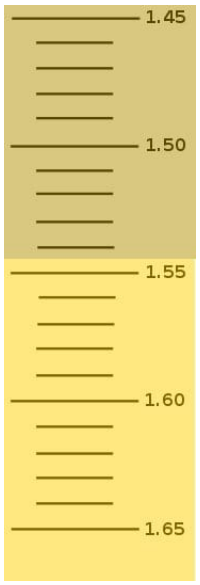


Figure 11.4.7***:*** *1.544*

We notate refractometer readings to a precision of 0.001 (one thousandths). The refractometer scale has subdivision indicators to 0.01 (one hundredths). Between the two horizontal bars which indicate the 0.01, you will need to estimate the final precision.

In the image on the right, you will see that the shadow edge is between the 1.54 and the 1.55 bars. Between these two values, we need to find the last precision. As it is just above the middle, the last precision is 0.004. So the reading is 1.544.

Estimating the last decimal needs some practice. Some refractometers, like the Eickhorst ones, have a more detailed division of the scales which makes taking a reading easier. With a little experience, you will find an easier-to-read scale is not needed.

Faceted gemstones

Following is the method for taking RI readings that is used for faceted gemstones. En-cabochon and sphere cut gemstones require a somewhat different technique which is explained in the "distant vision" section.



Figure 11.4.8***:*** *Starting position*
1st reading

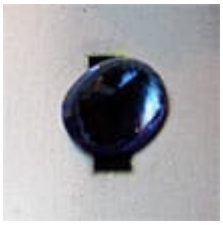


Figure 11.4.9***:*** *45-degree rotation*
2nd reading

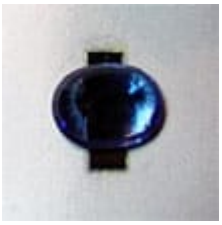


Figure 11.4.10***:*** *90-degree rotation*
3rd reading

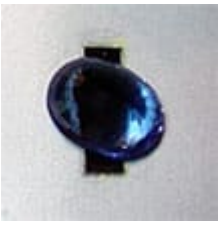


Figure 11.4.11***:*** *135-degree rotation*
4th reading

When taking refractometer readings, one usually starts with the largest facet (which is usually the table facet). Place your stone in the starting position, then close the lid of the refractometer. Make sure the light source is on.

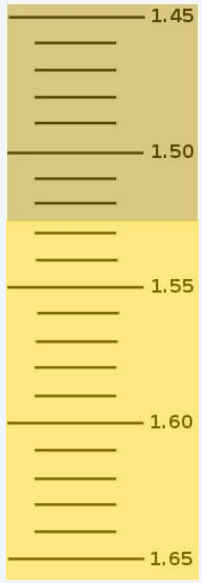
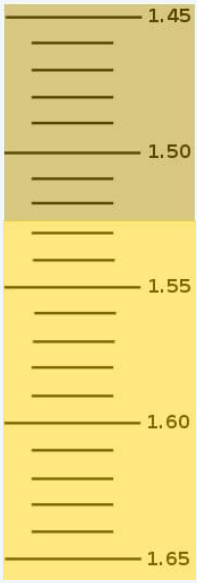
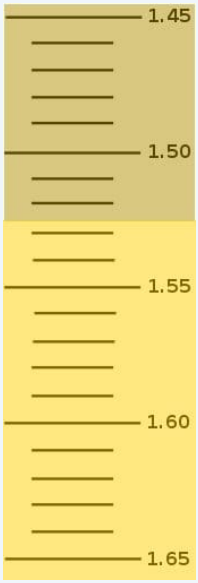
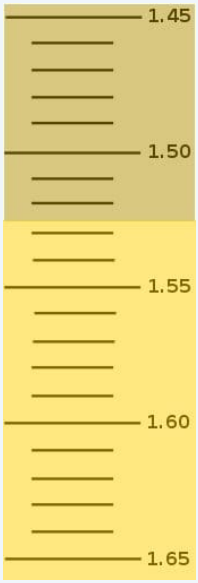
Position your eye in front of the ocular in a way so that it is at a straight angle with the refractometer scale. You will now most likely see a dark region at the top of the scale and a lighter region in the lower part. If you have chosen a monochromatic sodium light source, there will be a sharp line between the lighter and darker areas. That line is named the "shadow edge". (You may also observe 2 less sharp "shadow edges".)

Place the polarization filter on the ocular and, while looking at the scale, turn the polarizer 90 degrees left and right. You will observe either of two possibilities:

1. only one shadow edge is seen
   - the stone is either isotropic or
   - the incident light reaches the stone at an angle parallel to the optic axis and you should turn the stone 90 degrees
2. you see the shadow edge move between two values on the scale
   - the stone is uniaxial or
   - the stone is biaxial

- In the first case, where only one shadow edge is seen, the reading for the shadow edge will remain constant during a 135-degree rotation of the stone. For every rotation reading, take two measurements: one with the polarizing filter in North-South position and one with the polarizing filter in East-West position.

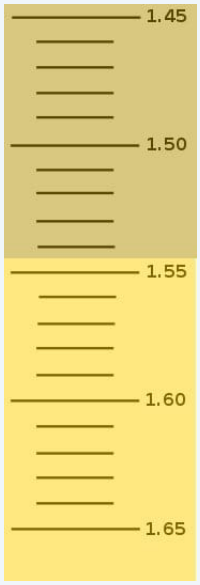
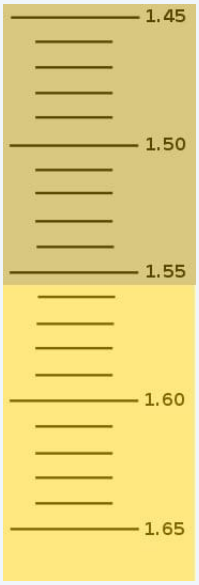
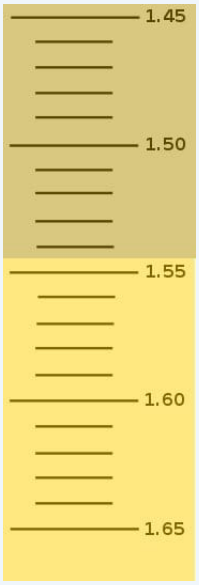
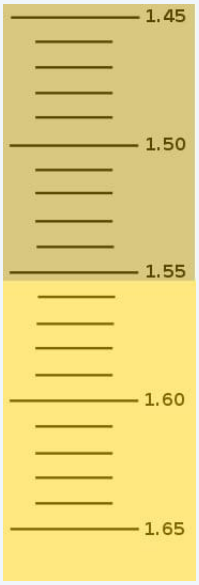
The readings in the images below indicate a single refractive (isotropic) stone with RI = 1.527, which is most likely glass. (If one finds a single refractive transparent faceted stone with an RI between 1.50 and 1.70, it is most likely glass). Taking four sets of readings (with the polarizer in both positions) on a single refractive stone looks like overkill, which it is; take them anyway.

First reading		Second reading		
				
1.527	1.527	1.527	1.527	1.

- In the second case, where the shadow edge moves between two values on the scale, write down both values you see, in table form below each other.

Below are 4 sets of readings of a double refractive stone with a uniaxial optic character (where one reading value remains constant). For every set of readings, you rotate the stone 45 degrees with your fingers without applying pressure while leaving the stone in contact with the hemicylinder.

First reading	Second reading	

				
1.544 ω	1.553 ε	1.544 ω	1.552 ε	1.5

	1st	2nd	3rd	4th
lower readings ω	1.544	1.544	1.544	1.544
higher readings ε	1.553	1.552	1.549	1.552

While taking your refractometer readings, write down the values you read on the scale. For every set of readings, the polarization filter is turned 90 degrees. In addition to this, you can also take a fifth reading (180-degree rotation).

In the example above, the lower readings (1.544) stay constant while the higher readings vary. In other gemstones, the higher value may remain constant while the lower value changes.

Note

The lower reading is the reading of lower value, not lower on the scale.

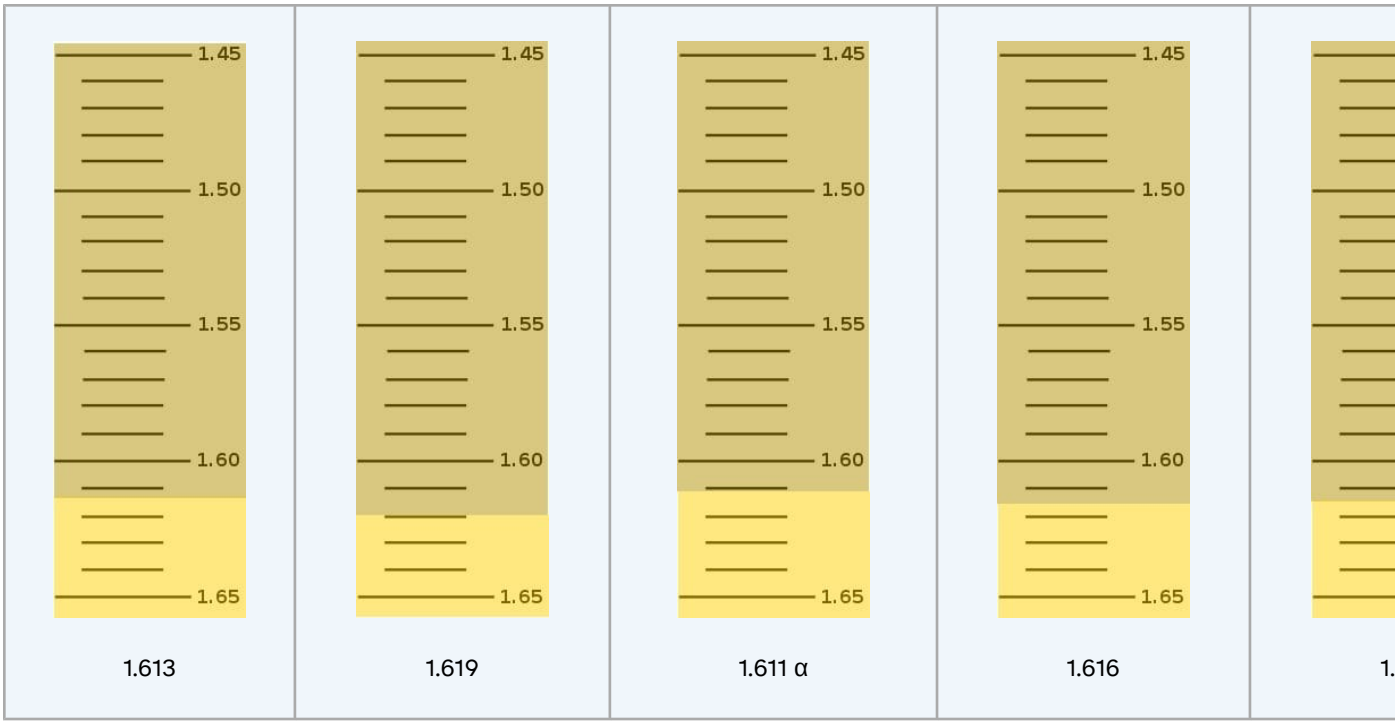
The RI of this stone is 1.544 - 1.553 (smallest lower reading and largest higher reading). This indicates quartz.

To calculate the birefringence of the gemstone being tested, you take the maximum difference between the largest higher reading and the smallest lower reading. In this example, that is 1.553 - 1.544 = 0.009 .

Some gemstones have a lower reading that falls within the range of the refractometer (and the liquid), while the higher reading falls outside the range. Those gemstones will give you just one reading on the refractometer and should not be confused with isotropic gemstones.

- Gemstones may also have two variable lower and higher readings, but the procedure remains the same. You write down the lower and higher readings in a table and calculate the birefringence.

First reading	Second reading	



These readings give a biaxial reading with RI = 1.611-1.620 and a birefringence of 0.009, indicating topaz.

	1st	2nd	3rd	4th	difference
lower readings	1.613	1.611	1.614	1.611	0.003
higher readings	1.619	1.616	1.619	1.620	0.004

You may have noticed some odd looking letters in the image footers, like α, γ, ε, and ω (and β which will be seen later on). They are not typos but Greek letters whose meanings will become apparent in the discussion on optical sign. You will also learn why we added the "difference" in the biaxial table.

Optical character

Optical character refers to how rays of light travel in gemstones (or most other materials).
In uniaxial and biaxial materials, the incoming light will be polarized in two (uniaxial) or three (biaxial) vibrational directions which all travel at different speeds inside the gemstone. This is due to the molecular packing inside the stone. For a better understanding, we refer to the discussion on double refraction.

Gemstones are divided into three categories (characters) depending on the way a ray of light behaves as it passes through the stone:

1. isotropic
2. uniaxial
3. biaxial

- Isotropic stones are stones in which light travels in all directions at equal speed.

  Among those stones are the ones that form in the cubic system as well as amorphous stones, like glass.

  - On the refractometer, you will see one constant reading.

- Uniaxial means that light travels differently in two directions.

  One ray of light will vibrate in the horizontal plane, which we call the ordinary ray (ω). The other will vibrate in a

vertical plane along the c-axis and is called the extra-ordinary ray (ε). This extra-ordinary ray is also the optic axis (the axis along which light behaves as if being isotropic).

Gemstones that are uniaxial by nature belong to the tetragonal, hexagonal and trigonal crystal systems.

• You will see one constant and one variable reading on the refractometer.

- Biaxial gemstones split up incoming light into two rays as well; however, the crystallographic directions are labeled as the α, γ, and β rays. The two rays both act as extra-ordinary rays.

  Stones with a biaxial optic character have two optic axes.

  The orthorhombic, monoclinic and triclinic crystal systems are biaxial.

  • This will be shown by two variable readings on the refractometer.

Spot readings (distant vision method)

This is the method used to estimate the RI of en-cabochon cut gemstones.

You place a very small drop of contact liquid on the hemicylinder and place the stone on the drop, on it's most convex side (as in the image below). Remove the polarization filter (if not already done) and close the lid.



Figure 11.4.12

Move your head back about 30 cm from the ocular and look straight to the scale. On the scale, you'll see a reflection of the contact liquid droplet. When you move your head slightly in a "yes-movement", you'll observe the droplet move over the scale. Try to fixate the point where half of the droplet is dark and the other half is bright.

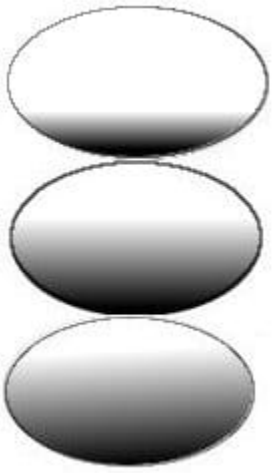


Figure 11.4.13

The image above shows three stages while moving your head. The top droplet is too light and the bottom one is too dark. The one

in the center shows a good half dark/half bright droplet.

Now move your head toward the ocular and estimate the Refractive Index. Unlike with faceted gemstones, we estimate to a 0.01 precision when using this method. The image below shows the reflection of the liquid which is half bright/half dark at 1.54. This gemstone may be Amber.

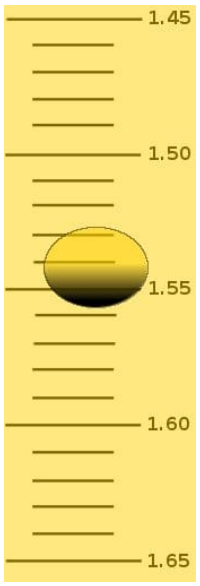


Figure 11.4.14

Alas, one cannot determine birefringence using this method, unless the birefringence is quite large (as with the carbonates). The "birefringence blink" or "carbonate blink" technique makes use of a larger drop of contact liquid and a polarizing plate. As the plate is rotated, the spot will be seen to blink. A crude estimation of birefringence can be made by this technique.

Advanced

Optical sign

Optic sign in birefringent gemstones is shown as either a plus (+) or a minus (-). The reasons why some stone have a positive sign and others a negative sign lies in the orientation of molecules inside the gemstone. This is explained by the use of an indicatrix in the refraction section.

Isotropic gemstones do not have an optical sign. Light travels at the same speed in all directions.

Uniaxial stones may have either a positive (+) optical sign or a negative (-) one.
We calculate the optic sign by deducting the ordinary ray (ω) from the extra-ordinary ray (ε). So in the case of Quartz with ε = 1.553 and ω = 1.544 that will give us a positive number of 0.009. Hence the optical sign is positive.
A full refractometer result for quartz will therefore be "RI = 1.553-1.544 uniaxial +" and a birefringence of 0.009.

In uniaxial gemstones, the constant reading is always the ordinary ray (ω).

If the ordinary ray is the higher reading in a gemstone (as in the case of Scapolite), there will be a negative optical sign. For instance if you have the following readings: ε = 1.549 and ω = 1.560, the calculation will be 1.549 - 1.560 = -0.011 (so a negative). This is how we separate Quartz from Scapolite most of the time, the first is uniaxial +, the latter is uniaxial -.

Biaxial gemstones can also be either positive or negative for the same reasons; however, biaxial minerals have three values that correspond with the crystallographic axes. These are the α (Greek letter alpha), β (Greek letter beta) and γ (Greek letter gamma). The indicatrix of biaxial materials is somewhat more complex than the uniaxial one.

In practice, we are not concerned with the intermediate β value, merely with the higher and lower readings we find on the

refractometer. As shown previous, we take 4 sets of readings for every orientation of the stone (0 degrees, 45 degrees, 90 degrees, and 135 degrees). If we put the readings in a nice table, we can calculate whether the higher or the lower readings vary the most.

	1st	2nd	3rd	4th	difference
lower readings α	1.613	1.611	1.614	1.611	0.003
higher readings γ	1.619	1.616	1.619	1.620	0.004

As can be seen in the table on the right, the higher readings vary the most (0.004) opposed to the lower readings (0.003), this indicates a positive sign. If the lower reading would have varied the most it would have been biaxial negative.
So for this Topaz, the full reading would be: "RI= 1.611-1.620 biaxial +" of course we also mention the birefringence as "DR = 0.009".

As a word of caution, the explanation above is a crude method as the β value has not been determined. When there is doubt about the identity of the gemstone due to the optic sign, make sure you determine the true value of β (here it could be either 1.614 or 1.616). When the polarizer is used properly, one will find that true β is at 1.614 for this stone.

Overview of the crystal systems

Structure	Structure type Crystal axes Angles	Symmetry (of highest crystal class)	Optic character	Refra
Amorphous	No order No axes	No symmetry	Isotropic Singly refractive	
Cubic	Isometric: 1 axis length $a_1 = a_2 = a_3$ All at 90°	13 planes 9 axes Center	Isotropic Singly refractive	
Tetragonal	Dimetric: 2 axis lengths $a_1 = a_2 \neq c$ All at 90°	5 planes 5 axes Center	Anisotropic Doubly refractive Uniaxial	n_w
Hexagonal	Dimetric: 2 axis lengths $a_1 = a_2 = a_3 \neq c$ a axes at 60°; c axis at 90° to their plane	7 planes 7 axes Center	Anisotropic Doubly refractive Uniaxial	n_w

Structure	Structure type Crystal axes Angles	Symmetry (of highest crystal class)	Optic character	Refra
Trigonal	Dimetric: 2 axis lengths $a_1 = a_2 = a_3 \neq c$ a axes at 60°; c axis at 90° to their plane	3 planes 4 axes Center	Anisotropic Doubly refractive Uniaxial	n_w
Orthorhombic	Trimetric: 3 axis lengths $a \neq b \neq c$ All at 90°	3 planes 3 axes Center	Anisotropic Doubly refractive Biaxial	n_a
Monoclinic	Trimetric: 3 axis lengths $a \neq b \neq c$ 2 axes at 90°; 1 axis oblique	1 axis 1 plane Center	Anisotropic Doubly refractive Biaxial	n_a
Triclinic	Trimetric: 3 axis lengths $a \neq b \neq c$ all axes oblique	No planes No axes Center	Anisotropic Doubly refractive Biaxial	n_a

Optic character/sign with the Refractometer

Optic character/curve variations: Uniaxial or biaxial

1. Two constant curves = Uniaxial

2. Two variable curves = Biaxial

3. One constant/one variable which meet = Uniaxial

4. One constant/one variable which don't meet:

Check the polaroid angle of the constant curve

a. Biaxial = polaroid angle of constant curve = 90°

b. Uniaxial = polaroid angle of constant curve ≠ 90°

Optic sign

Uniaxial stones

1. High RI curve varies = (+)

2. Low RI curve varies = (-)

3. Both curves constant: At 0° polaroid angle, only the o-ray is seen

a. If low curve is seen = (+)

a. If high curve is seen = (-)

Biaxial stones

1. If n_b is closer to n_a, the gem is (+)

2. If n_b is closer to n_g, the gem is (-)

3. If n_b is halfway between n_a and n_g, the gem is (±)

4. If two possible betas exist, false beta will have a polaroid angle equal to 90°. True beta will have a polaroid angle unequal to 90°.

Polaroid angle

- 0° polaroid angle is when the polarization axis of light transmitted through the plate is parallel to the refractometer scale divisions.
- 90° polaroid angle is when the polarization axis of light transmitted through the plate is perpendicular to the refractometer scale divisions.

Symbols

Uniaxial crystals

- n_w = omega, the constant RI of a uniaxial crystal
- n_e = epsilon, the variable RI of a uniaxial crystal

Biaxial crystals

- n_a = alpha, the lowest RI of a biaxial crystal
- n_b = beta, the intermediate RI of a biaxial crystal
- n_g = gamma, the highest RI of a biaxial crystal

Bright line technique

In some cases, you may find it very hard to get a clear boundary between light and dark using conventional refractometer techniques. In those rare cases you may find it useful to illuminate from the top of the hemicylinder instead of from below.

Cover up the illumination opening at the rear of the refractometer and open the lid. Place the stone in position as usual and illuminate the stone/hemicylinder in a way that the light is grazing over the surface of the hemicylinder.

This will give you a very bright area when you look through the ocular and/or a very bright line showing the RI value. This technique is best carried out in a dark environment with a light source that is pointed from the back of the stone (in the direction of the observer). The junction of the stone's facets should be perpendicular to the length axis of the hemicylinder.
With some practice, this will give you a 0.001 precision.

When allochromatic white light is used, one can determine the relative dispersion of the gemstone as well as absorption lines in some cases.

Kerez effect

Some green tourmalines may show up to 8 shadow edges (tourmaline is uniaxial and should only show two shadow edges in one reading). This is to current knowledge due to heat and/or thermal shock while polishing the table facets.
Little documentation on this subject is at hand.

Peter Read added the following in personal correspondence:
"The effect in green tourmaline was first reported in 1967 by R. K. Mitchell [ed.: Journal of Gemmology Vol. 10, 194 (1967)] and the name 'Kerez effect' was suggested by him. Work on the effect has since been carried out by Schiffmann and Prof. H. Bank. In GEMS, the effect first appeared in the 5th edition and was inserted in Chapter 6 (Topaz & Tourmaline) by the late Robert Kammerling former Director of Identification & Research, GIA Gem Trade Laboratory, USA. I understand that the effect is mainly caused by thermal shock due to polishing, and not to chemical constituents."

Dietrich [1985] mentions that the highest of these readings (lowest on the scale) are the correct ones.

This phenomenon was named after C.J. Kerez.

Different types of refractometers

A word of caution to all neophyte gemologists on buying a refractometer. Nowadays inexpensive refractometers are offered on the internet for as low as USD 100.00. They are mostly fabricated in China and one shouldn't expect too much from them. Especially obtaining an RI for small and en-cabochon cut stones may prove to be difficult.
Some sellers put their own respected company logo on them and pass them on as the best your money can buy.
Always test your new refractometer with a small stone with a known refractive index and make sure it is precise at 0.001.

Although the price is very tempting, a good refractometer is more costly but will last a lifetime when handled with care.
Some of them are outlined below.

The GemPro refractometer

GemPro refractometers are direct view type refractometers just like the duplex II that GIA makes. Direct view refractometers have removable eyepiece lenses that enable spot reading of cabochons. Other type refractometers can't do this well because they have a different prism design. The eyepiece used with the GemPro refractometer is a special achromatic lens that gives excellent resolution when birefringence and other readings are being observed. The hemicylinders are made of a special German glass made by Schott glass company. These hemicylinders are tough to scratch and resistant to chemicals. Tarnish from the air does not happen with this type of glass. Supplied with monochromatic filter, RI liquid, and MagLight.

The Rayner Dialdex refractometer

This refractometer differs from most TIR refractometers that it doesn't have an internal scale to read the values from. Instead, you will see a "window" with a bright area. By turning a "wheel" on the side of the refractometer, a vertical black band will appear which should be lined up with the lower edge of the bright area. After this one takes the reading from the calibrated wheel.
An external light source should be used.

The Duplex refractometer

Made in the USA, this refractometer has an extra large window of view. Making it easier to find shadows.
No built-in light source, an external one should be used.

The Eickhorst refractometer

In contrast to most refractometers, the Eickhorst refractometers have a calibrated scale with 0.005 precision (opposed to the usual 0.01) and this makes estimating the third decimal easier.
Eickhorst also offers gemology modules of great quality and appealing appearance. Some models have an internal light source.

The Topcon refractometer

This refractometer is made in Japan. Very sturdy metal case and made to last. It is one of the most expensive refractometers on the market.
No internal light source.

The Kruess refractometer

Kruess is a long-established German manufacturer of all sorts of refractometers (not only for gemological purposes). Their line in excellent gemological refractometers includes portable and standard ones, with or without built-in lightning.

Refractive Index of Common Gem Minerals

Some of the values listed below reflect values which are extreme possibilities for the gem.
In other words, highs and lows which are, but rarely, seen.
Remember to always check values for birefringence, as it can be as diagnostic as RI.

Gem Mineral	Refractive Index
Actinolite	1.614 - 1.655
Adventurine (Quartz)	1.544 - 1.553
Agate	1.535 - 1.539
Air (as a point of interest)	1.0003
Albite (Feldspar)	1.527 - 1.538
Alexandrite	1.745 - 1.759
Allanite	1.640 - 1.828
Almandine (Garnet)	1.775 - 1.830
Amazonite (Feldspar)	1.514 - 1.539
Amber	1.539 - 1.545
Amblygonite	1.578 - 1.612
Amethyst	1.544 - 1.533
Ametrine	1.544 - 1.553
Anatase	2.488 - 2.564
Andalusite	1.627 - 1.650
Andesine (Feldspar)	1.543 - 1.551
Andradite (Garnet)	1.880 - 1.940
Angelsite	1.877 - 1.894
Anorthite (Feldspar)	1.577 - 1.590
Apatite	1.628 - 1.650

Apophyllite	1.530 - 1.540
Aquamarine (Beryl)	1.567 - 1.590
Aragonite	1.530 - 1.685
Augelite	1.574 - 1.588
Axinite	1.672 - 1.694
Azurite	1.720 - 1.850
Barite	1.636 - 1.648
Bastnäsite	1.717 - 1.818
Benitoite	1.757 - 1.804
Beryl	1.563 - 1.620
Beryllonite	1.552 - 1.562
Bixbite (Beryl)	1.568 - 1.572
Boracite	1.658 - 1.673
Brazilianite	1.602 - 1.625
Bronzite	1.665 - 1.703
Bytownite (Feldspar)	1.561 - 1.570
Calcite	1.486 - 1.740
Carnelian	1.535 - 1.539
Cassiterite	1.995 - 2.095
Celestite	1.619 - 1.635
Cerussite	1.803 - 2.078
Chalcedony	1.535 - 1.539
Chrome Diopside	1.668 - 1.702
Chrysoberyl	1.740 - 1.777
Chrysocolla	1.575 - 1.635
Chrysoprase	1.535 - 1.539
Citrine	1.544 - 1.553
Clinozoisite	1.670 - 1.734
Colemanite	1.586 - 1.614
Coral	1.550 - 1.580
Crocoite	2.290 - 2.660
Cubic Zirconia	2.170
Cuprite	2.848
Danburite	1.627 - 1.639
Datolite	1.621 - 1.675
Demantoid (Andradite)	1.880 - 1.888
Diamond	2.417
Diopside	1.664 - 1.721

Dioptase	1.645 - 1.720
Dolomite	1.500 - 1.703
Dumortierite	1.668 - 1.723
Ekanite	1.590 - 1.596
Emerald (Beryl)	1.575 - 1.602
Emerald (synth. flux)	1.553 - 1.580
Emerald (synth. hydro)	1.563 - 1.620
Enstatite	1.650 - 1.680
Epidote	1.715 - 1.797
Euclase	1.650 - 1.677
Fayalite (Olivine)	1.827 - 1.879
Fluorite	1.432 - 1.434
Friedelite	1.625 - 1.664
Gahnite	1.790 - 1.820 (isometric)
Gahnospinel	1.735 - 1.790
Genthelvite	1.742 - 1.745
Glass (man-made)	1.520 - 1.550
Gold	0.470
Goshenite (Beryl)	1.566 - 1.602
Grossular (Garnet)	1.730 - 1.760
Hackmanite	1.483 - 1.487
Hambergite	1.550 - 1.630
Hauyne	1.496 - 1.505
Heliodor (Beryl)	1.566 - 1.579
Hematite	2.880 - 3.220
Hemimorphite	1.614 - 1.636
Hessonite (Garnet)	1.742 - 1.748
Hiddenite (Spodumene)	1.653 - 1.682
Howlite	1.583 - 1.608
Hydrogrossular (Garnet)	1.690 - 1.730
Hypersthene	1.686 - 1.772
Idocrase	1.655 - 1.761
Iolite	1.533 - 1.596
Ivory	1.535 - 1.555
Jadeite	1.640 - 1.667
Jasper (Quartz)	1.544 - 1.553
Kornerupine	1.665 - 1.700
Kunzite (Spodumene)	1.653 - 1.682

Kyanite	1.710 - 1.735
Labradorite (Feldspar)	1.560 - 1.572
Lapis Lazuli	1.500
Lazulite	1.604 - 1.662
Leucite	1.504 - 1.510
Magnesite	1.509 - 1.717
Malachite	1.655 - 1.909
Maw-Sit-Sit	1.520 - 1.680
Microline (Feldspar)	1.514 - 1.539
Moissanite	2.648 - 2.691
Moldavite	1.460 - 1.540
Moonstone (Feldspar)	1.518 - 1.526
Morganite (Beryl)	1.572 - 1.600
Natrolite	1.473 - 1.496
Nephrite	1.600 - 1.640
Obsidian	1.450 - 1.520
Oligoclase (Feldspar)	1.542 - 1.549
Onyx	1.535 - 1.539
Opal	1.370 - 1.470
Orthoclase (Feldspar)	1.518 - 1.539
Painite	1.787 - 1.816
Pearl	1.530 - 1.685
Pectolite	1.595 - 1.645
Periclase	1.736
Peridot (Olivine)	1.650 - 1.681
Petalite	1.502 - 1.520
Phenakite	1.650 - 1.695
Phosphophyllite	1.595 - 1.621
Prasiolite (Quartz)	1.544 - 1.553
Prehnite	1.611 - 1.665
Proustite	2.792 - 3.088
Purpurite	1.850 - 1.920
Pyrope (Garnet)	1.730 - 1.766
Quartz	1.544 - 1.553
Rhodizite	1.694
Rhodochrosite	1.578 - 1.840
Rhodolite (Garnet)	1.745 - 1.760
Rhodonite	1.711 - 1.752

Ruby (Corundum)	1.762-1.770
Rutile	2.620 - 2.900
Sanidine (Feldspar)	1.518 - 1.534
Sapphire (Corundum)	1.762-1.770
Sapphirine	1.714 - 1.723
Scapolite	1.536 - 1.596
Scheelite	1.918 - 1.936
Serpentine	1.490 - 1.575
Shattuckite	1.752 - 1.815
Siderite	1.633 - 1.873
Sillimanite	1.654 - 1.683
Silver	0.180
Sinhalite	1.665 - 1.712
Smithsonite	1.620 - 1.850
Sodalite	1.483 - 1.487
Spessartine (Garnet)	1.790 - 1.810
Sphalerite	2.400
Sphene	1.900 - 2.034
Spinel	1.712 - 1.735 (isometric)
Spinel (syn. flame fushion)	1.710 - 1.740 (isometric)
Spodumene	1.653 - 1.682
Staurolite	1.736 - 1.762
Strontium Titanate	2.400
Taaffeite	1.717 - 1.730
Tantalite	2.260 - 2.430
Tanzanite (Zoisite)	1.692 - 1.705
Tektite	1.460 - 1.540
Thomsonite	1.497 - 1.544
Thulite (Zoisite)	1.692 - 1.705
Tiger eye (Quartz)	1.544 - 1.553
Topaz	1.609 - 1.643
Tourmaline	1.620 and 1.640 (usually)
Tremolite	1.560 - 1.643
Tsavorite (Garnet)	1.560 - 1.643 (isometric)
Tugtupite	1.494 - 1.504
Turquoise	1.610 - 1.650
Ulexite	1.496 - 1.519
Uvarovite (Garnet)	1.740 - 1.870 (isometric)

Vanadinite	2.350 - 2.416
Variscite	1.560 - 1.594
Vesuvianite	1.655 - 1.761
Vivianite	1.569 - 1.675
Water (at 20°C)	1.3328
Willemite	1.690 - 1.723
Wulfenite	2.280 - 2.405
Zincite	2.013 - 2.029
Zircon, High	1.970 - 2.025
Zircon, Medium	1.840 - 1.970
Zircon, Low	1.780 - 1.850
Zoisite	1.685 - 1.725

Related Topics

- Refraction
- Brilliance
- Dispersion
- Interference
- Immersion cell

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11.05: Polariscope

The polariscope may be one of the most underestimated tools in gemology. Most gemologists use it to quickly determine if the stone at hand is isotropic or anisotropic or, at best, to determine the optic character of gemstones. With some small additions, one can determine both optic character and the optic sign of a gemstone. It is also the preferred tool -- next to the microscope -- for separating synthetic amethyst from its natural counterparts (although with recent synthetics that may prove difficult).
In addition, the polariscope may be very useful for distinguishing solid inclusions from negative inclusions as well as for spotting polysynthetic twinning.

Basic



Figure 11.5.1***:*** *The polariscope*

A polariscope uses polarized light for gem identification. It consists of two polarized filters, one on the top and one on the bottom of the instrument as seen in the picture to the right. Both the polarizer and the analyzer have their own vibrational planes. When the vibrational plane of the polarizer is at right angles to the vibrational direction of the analyzer, the field between them remains dark. This position is known as the "crossed position". In this position, gems can be tested to determine if they are:

- isotropic
- anisotropic
- anomalously double refractive or an
- anisotropic aggregate

The polarizing filters of this instrument are made of polarizing plastic sheets (polyvinyl alcohol containing dichroic molecules - stretched polymers). Older models were created with microscopically oriented crystals of iodoquinine sulfate (herapathite) or tourmaline plates.

Operation of the polariscope and possible observations

With the polarizer and analyzer in the crossed position, turn on the light source and place the gemstone on the rotating platform just above the polarizer (this platform might not always be present, in which case you use your tweezers).
Observing the gemstone through the analyzer while slowly turning the stone will give you 4 possibilities.

1. The stone appears dark throughout a 360° rotation.

    The stone is isotropic (single refractive).

2. Throughout a 360° rotation the stone blinks 4 times, light and dark.

    The stone is anisotropic (double refractive).

3. The stone will appear light all the time.

The stone is a microcrystalline or cryptocrystalline aggregate (like, for instance, chalcedony).

4. The stone will show anomalous double refraction (ADR).

It is isotropic (single refractive).

The first 3 behaviors should pose no problems for the inexperienced user, but the latter (ADR) can be misinterpreted and cause one to think the stone is double refractive.

Video presentations

Video 11.5.1***:*** *Video illustrating the use of the polariscope to determine optic character*

Video 11.5.2***:*** *Video showing the behavior of double refractive stones and ADR under the polariscope*

A possible solution for overcoming the confusion when one suspects ADR is to orientate the stone in its lightest position and then quickly turn the analyzer 90°. If the stone becomes noticeably lighter, it means the gemstone is single refractive and is exhibiting ADR. If it stays more or less the same, the stone is double refractive.

Red stones that are out of the limit of the refractometer (OTL) may be especially difficult to distinguish with the polariscope due to ADR. Some stones in this category are ruby, red spinel and red garnets.

Note

It should be noted that the gem being examined should be transparent to translucent so light can pass through it. If you put a piece of floor tile under the polariscope it would remain dark, but that doesn't mean the tile is single refractive. It just means light can’t pass through it.

An anisotropic gemstone can have one direction or two in which it will stay dark throughout lateral rotation. These directions are the optic axes of the gemstone. Uniaxial stones have one optic axis, biaxial gemstones have two. No double refraction occurs along the directions of optic axes.
Because there may be more than one direction in which some gemstones remain dark, it is useful as a confirmation to view the stone under a different angle when it stays dark.

Advanced

Polarizing microscope

With the aid of a few polarizing sheets, one can turn the gemological microscope into a polarizing microscope for less than USD 30.00.
Simply lay one of the sheets over the transmitting light source and tape the other one in the crossed position below the optics (or find your own way of doing something similar).
This enables us to distinguish between solid and negative crystal inclusions and many other internal features a gemstone might have.

A lot of the following discussion involves such a setup, although most of it can be achieved with the usual gemological polariscope as well.

Conoscopy



Figure 11.5.2***:*** *Conoscope*

In gemology, we use a conoscope (a strain-free acrylic or glass sphere on a rod) to determine optic character (uniaxial or biaxial) in anisotropic gemstones. The conoscope creates a 2-dimensional image of the 3-dimensional interference in a mineral.
Although determining the optic character with a conoscope is a fairly easy procedure, finding the interference figure itself is not. The interference figures always appear around the optic axes of minerals.

The simplest way to find an interference figure is to rotate the stone under the polariscope, in every possible direction, while looking down the analyzer until one sees a small flash of colors appear on the surface of the gemstone. When that flash of colors is found, fix the stone in that position and hover your conoscope slightly over it. Now, while still looking through the analyzer, you should see the color flash transform into a rounded 2-dimensional image.
This image in uniaxial stones will appear different from the image in biaxial stones, each having its own characteristic pattern.

Using an immersion cell along with the polariscope may enable you to find the flash figures more rapidly.

Due to enantiomorphism, quartz will give a typical uniaxial image but with a large "target" in the middle. That is what is named a "bull's eye" and is typical for quartz (both natural and synthetic).

Because anisotropic minerals appear to be single refractive when viewed down the optic axis, another technique for finding the optic axis can be used. View the stone under the polariscope from all sides to find where the gemstone does not blink light and dark on lateral rotation. That will be the optic axis.
Remember that uniaxial minerals have one optic axis while biaxial gemstones have two optical axes.

Many polariscopes for gemological purposes come with a rather large conoscope that can be swiveled like a gemstone holder. Although one can get reasonably nice images with them, a conoscope rod is preferred and the smaller the sphere, the sharper the image. For the very small spheres, one will need magnification to observe the interference figure.

Interference figure nomenclature

For clarity, the nomenclature of interference figures should be understood. Luckily this is not too difficult.

In uniaxial stones, the "melatope" indicates the center of the dark cross and is the direction of the optic axis (looking down the optic axis).
The dark cross is actually made up of two L-shaped "isogyres" that will always stay in the same position in uniaxial stones.
The colored concentric fringes are named "isochromes".

Biaxial minerals have two optic axes, hence they have two "melatopes" that are in the center or the isogyres.
Again the dark cross is made up of two brushes, named "isogyres".
The colored concentric fringes are named "isochromes".

When the biaxial interference figure is laterally turned, the isogyres detach and transform into hyperbolas. The maximum curvature of these hyperbolic isogyres is at 45° rotation.
The distance between the two melatopes is dependent on the "2V" value of the mineral. When this 2V value is large (about 40-50°), the two isogyres will rarely ever be seen in one image. This also depends on the "numerical aperture" of your microscope.
No knowledge of "2V" or "numerical aperture" is needed for our discussion.

Retardation

In mineralogy, retardation means that one refracted ray of light is lagging behind another ray of light.
When light enters an anisotropic (double refractive) gemstone, it is split into two rays -- a fast ray and a slow ray. Because the fast ray travels faster through the gemstone it will be ahead of the slow ray. When the slow ray leaves the gem, the fast ray would have already traveled an extra distance outside the gemstone. That extra distance is known as "retardation" and is measured in nm (nanometers).

Through a series of calculations, it is shown that this retardation is dependent on the thickness and birefringence of the gemstone.

When the stone is placed between two polarizing filters (a polariscope), the two rays combine at the analyzer and either interfere with each other or cancel each other out, depending upon whether the rays are in phase or out of phase. This produces the typical interference colors.
These colors show a distinct pattern and, again, depend on the thickness and birefringence of the material.

As the thickness of the gemstone increases, the colors shift toward the right.
This knowledge can be useful in gemology as one could also add another mineral on top of the gemstone to mimic increased thickness and thus create a shift in colors when viewed through the conoscope. This shift can either be to the left or to the right. When the slow ray of the gemstone and the slow ray of the added mineral align, the shift will be to the right. This will create an addition in color on the Newton Color Scale. When the slow ray of the gemstone and the fast ray of the added mineral align, the shift will be to the left and will create a subtraction in color.

When, for instance, a gemstone would create a retardation of 550nm, the starting spectrum would be on the boundary of the first order and second order and go from magenta to blue to blue-green to yellow to red. Then if a mineral with a retardation of 137nm is added, and if the slow ray of the gemstone aligns with the slow ray of the added mineral, the starting color would be blue (at 687nm) instead of magenta.
On the other hand, if in the same example the slow ray of the gemstone would align with the fast ray of the added mineral, there would be a subtraction, and then the starting color would be (550-137) 413nm -- yellow-orange.

Retardation Plates

Normally, we don't know what the slow ray or the fast ray is for a particular gemstone nor for the added mineral, so this knowledge is of little use because of these two uncertain variables. To remove this uncertainty, "retardation plates" are made.

Retardation plates (as those added minerals are known) have a known retardation, and the vibrational directions of the slow and fast rays are known. This can help us determine the optic sign in gemstones.

Mineralogists generally use 3 kinds of retardation plates:

- quarter wave plates (with a retardation of 137nm) - made from mica
- full wave plates (with a retardation of 550nm) - made from gypsum
- quartz wedges (with an increasing retardation of 0 to 550nm) - made from quartz

All of the above plates can be very expensive since they are usually designed for petrographical microscopes that require special slots in the microscope. Fortunately, modern-day technology has created anisotropic plastic substitutes that cost little and can be held between your fingers. These plastic plates can be used in conjunction with the standard polariscope or with an adapted gemological microscope where polarizing filters are placed just above the light source at the base and just below the optics (you

can use tape to hold them in place).
The latter is a setup that transforms your microscope into a polarizing microscope, at low cost, with the great benefit of magnification.

Those plastic retardation plates can be obtained from various sources (like the Daly/Hanneman simulated quartz wedge from Hanneman Gemological Instruments) at low cost. If you are intent on buying a plate, make sure you know how the fast and slow rays are orientated. With a stone of known optic sign you can determine that yourself though.

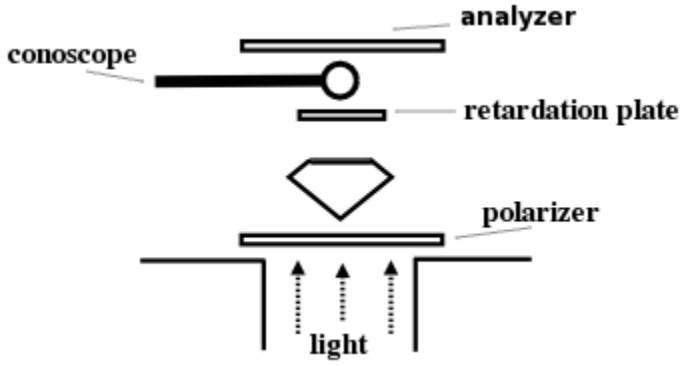


Figure 11.5.3***:*** *Typical polariscope setup with conoscope and retardation plate*

Determining optic sign with the use of retardation plates

Determining the optic sign in anisotropic gemstones should pose few problems with the aid of one of the retardation plates. The real challenge, however, is finding the interference figure.
All images below are conoscopic images (with the conoscope in place).

The plates should be placed directly under or directly above the gemstone. When above the gemstone, the plate should be placed between the stone and the conoscope.

The plate itself should be inserted at a 45° angle to the polarizer and analyzer as illustrated in the images below.

Full wave plate on uniaxial stones

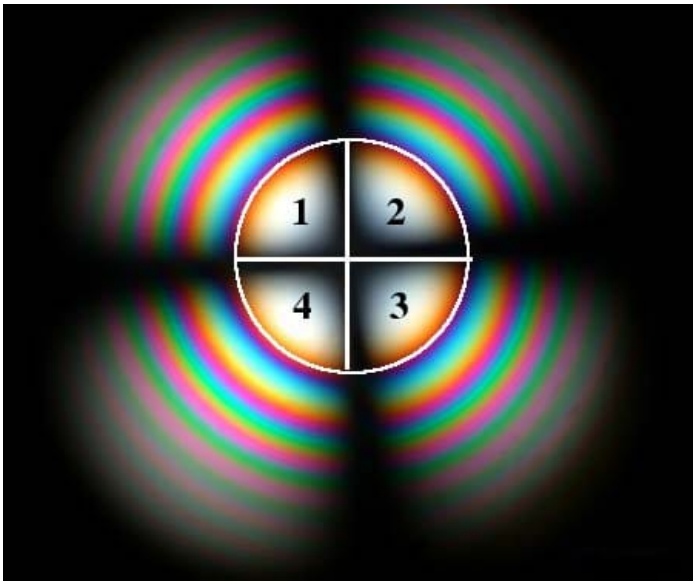


Figure 11.5.4

For convenience, the image above has the area of interest marked, which is the area just around the center of the interference figure (the white circle).
That area is divided into 4 quadrants.

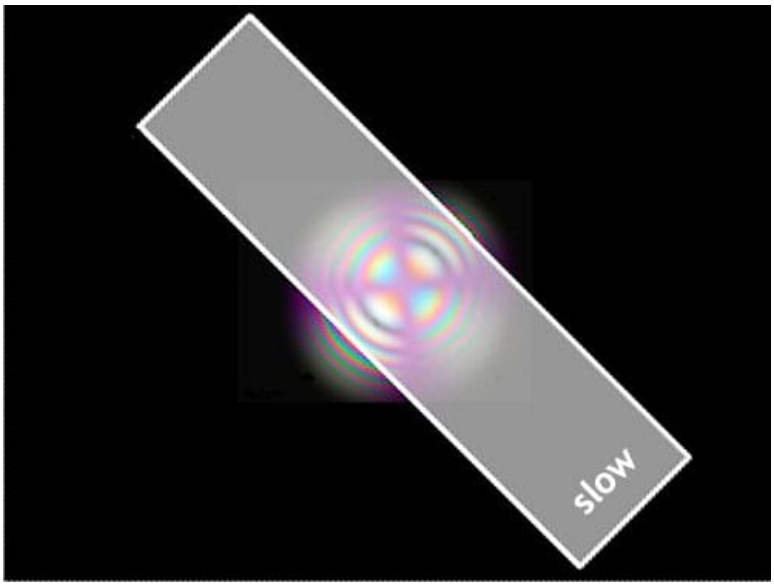


Figure 11.5.5

The full wave plate is inserted from bottom right to top left at an angle of 45°.
In the direction marked "slow", the slow ray of the wave plate travels. The fast ray travels in the direction of the length of the plate.

When one looks closely (click the image for a clearer, larger view) the colors in the quadrants change.
Quadrants 1 and 3 turn more or less blue (here addition of color occurred), while in quadrants 2 and 4 the colors change to predominantly yellow-orange (here subtraction occurred).

This indicates a uniaxial gemstone with a **negative** optic sign.

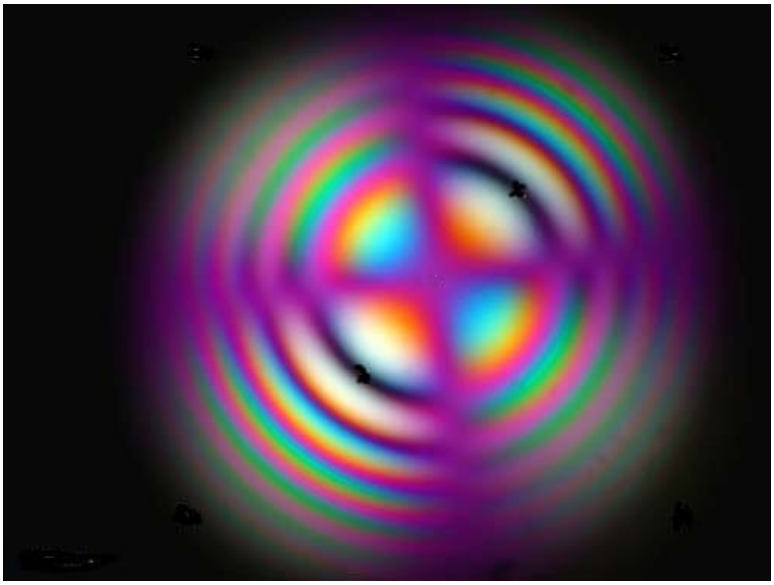


Figure 11.5.6

The wave plate removed for a clearer view (this is for illustration only and will not work in practice).

The quadrants 1 and 3 clearly have a shift of color to blue. Also, notice that the dark cross (the isogyres) now have a magenta color. This is caused by the magenta color of the full wave plate under crossed polars (the color in natural daylight is transparent white).

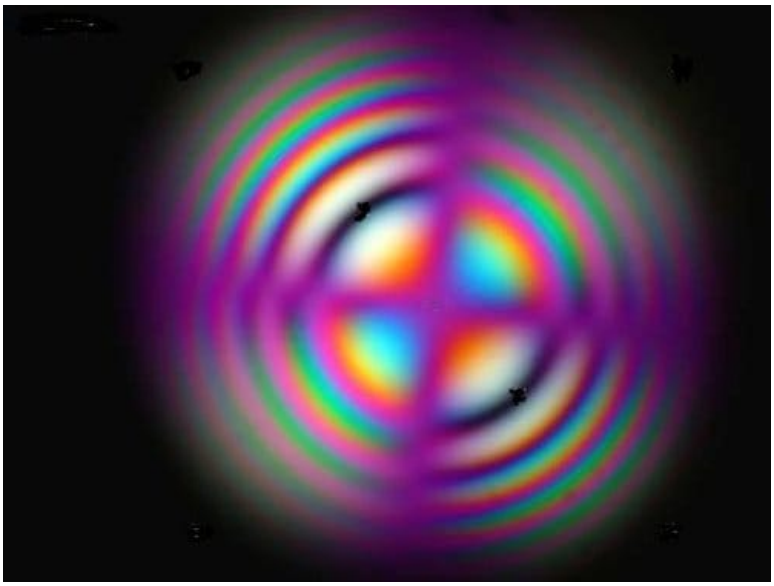


Figure 11.5.7

The opposite of the above. Quadrants 1 and 3 show a yellow-orange color, while quadrants 2 and 4 turn blue.

This indicates a uniaxial stone with a **positive** optic sign.

Full wave plate on biaxial stones

The full wave plate is best operated on biaxial gemstones which are orientated in a way that the isogyres are at 45° to the polarizing filters.
We concentrate on the areas just around the melatopes in the isogyre.

The areas in question (on the convex and concave sides of the isogyre) are more or less gray. These colors will change when a full wave plate is inserted.

Ideally, a biaxial gemstone will show both isogyres in one image, but alas that is not always the case.
As with the uniaxial stones, the wave plate is inserted at 45° to the polarizing filters.

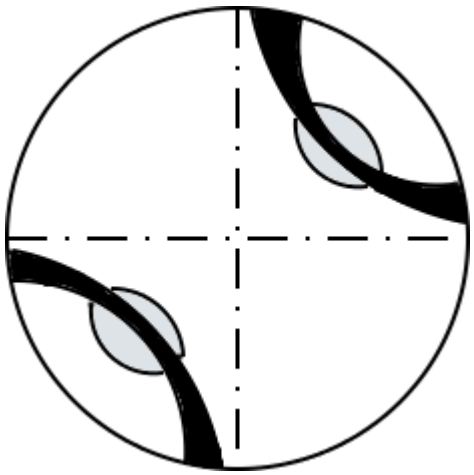


Figure 11.5.8***:*** *Rotation of 45° with isogyres at maximum curvature. Colors on convex and concave sides are of 1st order gray.*

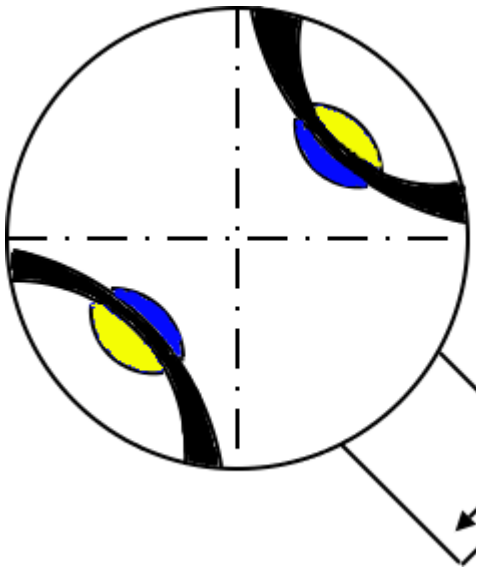


Figure 11.5.9***:*** *Inserted full wave plate creates blue co sides of the isogyres and yellow on the conca*

This indicates a ***negative*** *optic sign*

Most of the time, you will see only one of the isogyres at one time. When you do, rotate it to maximum curvature as seen in the images below.
When the 2V values are high (close to 90°), the curvature is almost impossible to recognize and you will have a hard time trying to see which direction it curves to (up or down). At other times, the isogyre is a very fuzzy hyperbole which gives the same troubles. With practice, you will be able to recognize it more rapidly.

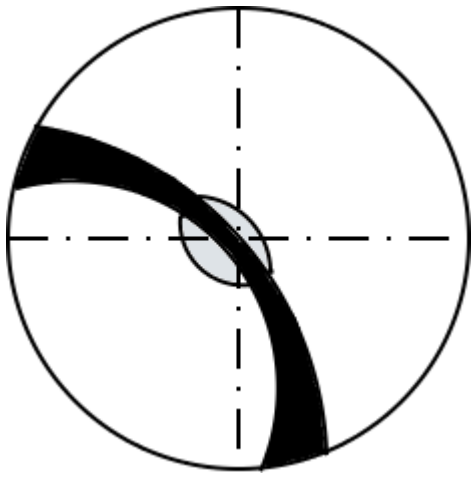
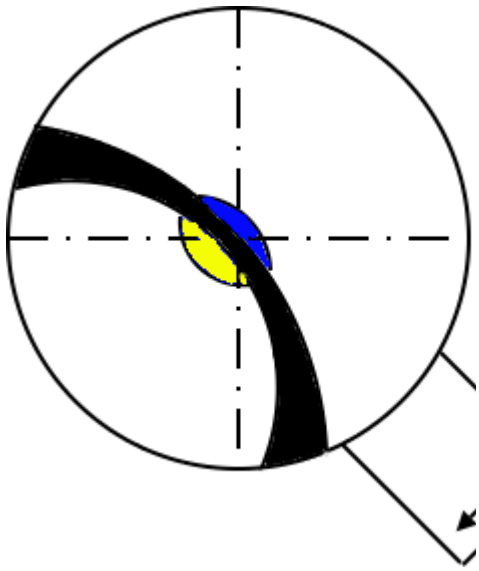


Figure 11.5.11***:*** *Without full wave plate inserted*



Same situation as above with the focus on on

Figure 11.5.12***:*** *Optic sign is* ***negative***

Quarter wave plates

Quarter wave plates work in a similar way as full wave plates but will produce different images.
These plates are traditionally made from thin sheets of mica with a retardation of approx. 137 nm (a quarter of a full wave plate). Plastic simulators are available and even cellophane the florist wraps flowers in can act as a quarter wave plate. In the latter case, the fast ray of the cellophane is in the direction of the roll.

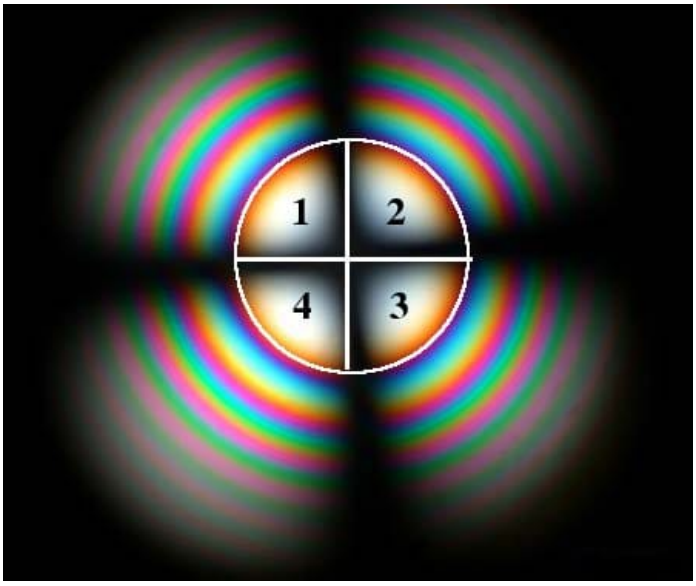


Figure 11.5.14

As discussed previously with the full wave plate, the conoscopic image of this uniaxial stone is divided into 4 imaginary quadrants.

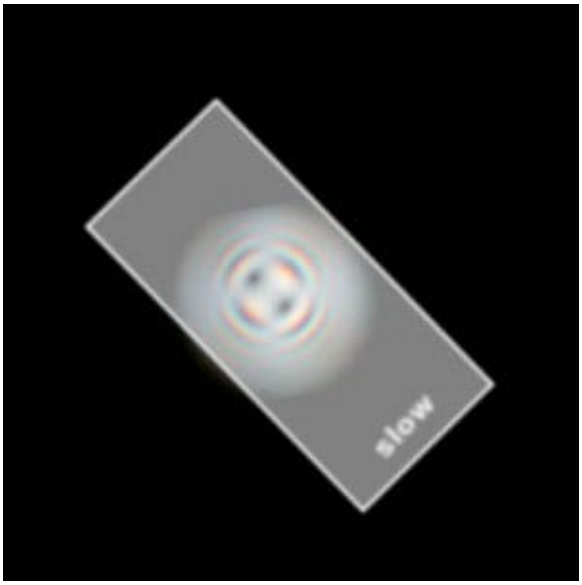


Figure 11.5.15

The quarter wave plate is inserted at a 45° angle to the polarization filters and two black spots appear in the 1st and 3rd quadrants. This indicates a uniaxial gem with a **positive** optic sign.
For uniaxial negative stones, the black spots will be seen in the 2nd and 4th quadrants.

As before, the fast ray travels along the length of the wave plate.

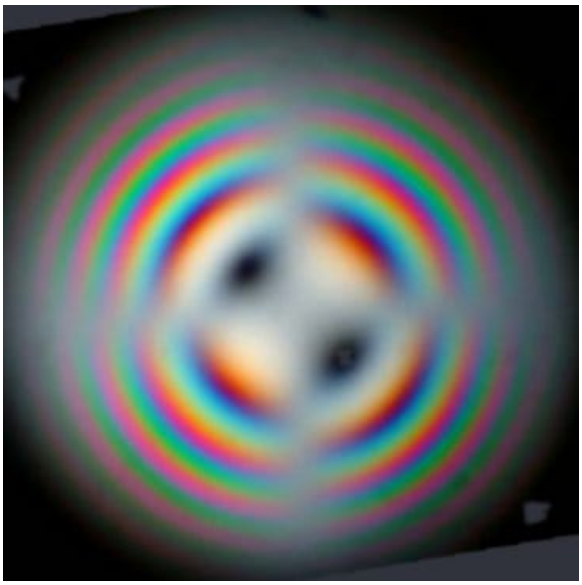


Figure 11.5.16

Same image as above, but enlarged and the waveplate removed for a better view (for illustration purposes only).

Airy Spirals

Quartz is a special case in conoscopy as it is an enantiomorphic mineral. This means that the crystal structure spirals either to the left or to the right along the direction of the optic axis, resulting in the typical "bulls-eye" under the conoscope.
With the addition of a quarter wave plate this bulls-eye transforms in two spirals which spiral either to the left or right, showing their "handedness". These spirals are named "Airy Spirals" after Sir George Biddell Airy who first described this in 1831.
Some quartz (especially amethyst) is both right-handed as left-handed due to Brazil twinning. As a result, it will not show the typical bulls-eye but a combination of the left and right Airy Spirals (4 spirals in total) under the conoscope. This may look very much like the classical bulls-eye in faceted stones, especially when the optic axis cuts through small facets. One doesn't need a retardation plate to observe the latter.

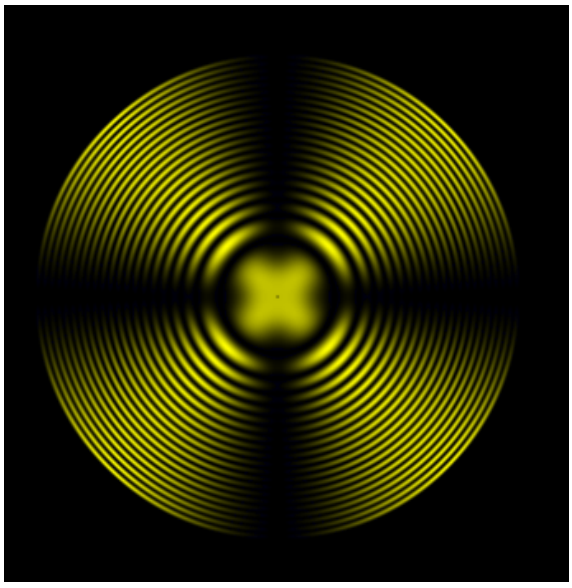


Figure 11.5.17**:** Bulls-eye in monochromatic light, either left or right-handed.

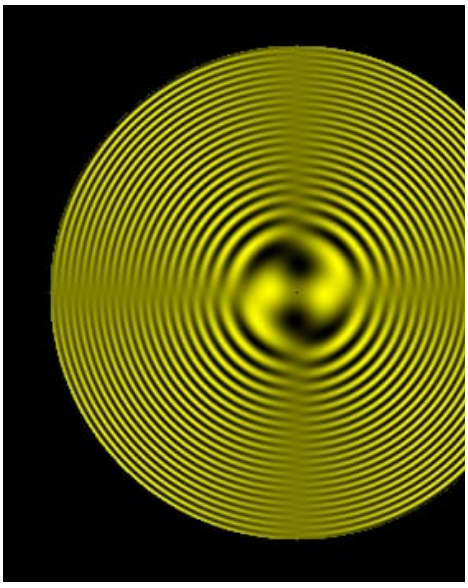


Figure 11.5.18**:** With the quarter wave inserted the Air
left.
This indicates left-handed quartz

Quartz Wedges

With quartz wedges, the movement of the isochromes becomes important in determining optic sign.

Quartz wedges are wedges made of the mineral quartz. The increasing thickness of the wedge provides for a continues range of retardation between, usually, 0 and 550 nm. This means that the wedge can be used as a quarter wave plate as well as a full wave plate. The wedge is not used as such mostly in gemology; instead, it is used to hover over an interference pattern and to determine optic sign by observing the movement of the isochromes.

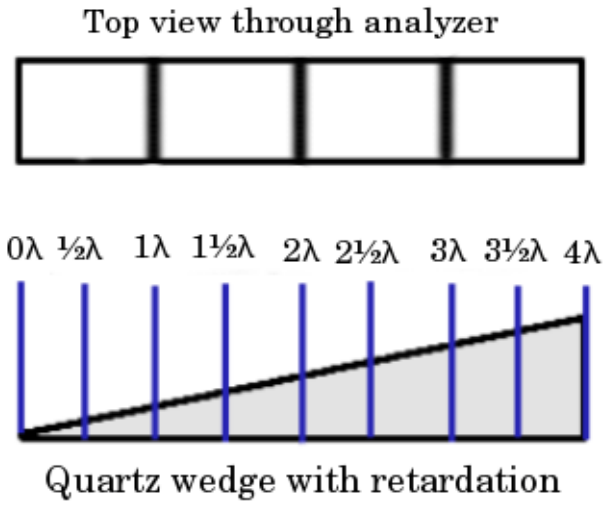


Figure 11.5.20***:*** *Quartz wedge in top view between crossed polarizers and side view with the relative retardation wavelengths indicated*

As real quartz wedges are very expensive, small and mainly made for use in petrographical microscope this technique was not practiced a lot by gemologists. Luckily one can now buy inexpensive (around USD 40.00) plastic sheets that can do the same. The first (or at least the first reported) one who used these polystyrene plastic simulated quartz wedges was Pat Daly, FGA from England. He constructed the first ones from the clear boxes in which the OPL spectroscopes are shipped in.
Dr. Hanneman made this tool semi-popular and the plastic quartz wedge is now named the "Hanneman-Daly wavelength modifier & simulated quartz wedge".

A few hours of practice should be enough to master this technique and it may come in very handy when you can perform little other tests.

Uniaxial stones and the quartz wedge

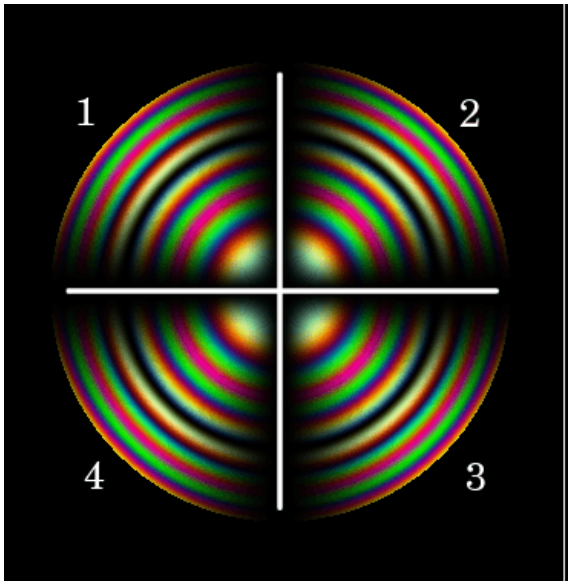


Figure 11.5.21

We now divide the whole conoscopic interference pattern into 4 sections (not just the center).

Although these images show perfect computer generated interference patterns, one can easily find the optic sign on a partial image.

When you don't know the orientation of the polarizer and the analyzer of your polariscope, all you need to do is look at the cross in the uniaxial interference figure. The crosses indicate the vertical and horizontal alignments (also indicated by the white lines). If the dark cross is not horizontal/vertical that means neither are your polarizers. That isn't very important, just make sure you adjust the position of the wedge (or any other wave plate) accordingly.

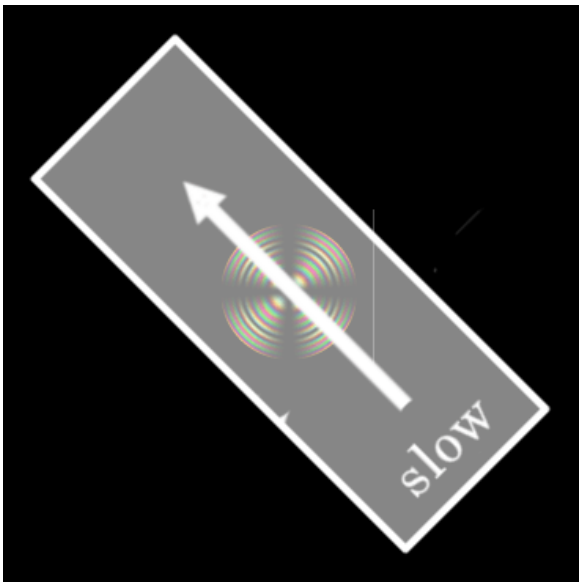


Figure 11.5.22

The simulated Hanneman-Daly quartz wedge is inserted as shown, 45° to the polarizer and analyzer, and one needs to slowly move it along the direction of the arrow over the pattern (from quadrant 3 to quadrant 1). The arrow is only there to show the direction of movement, it isn't on the wedge itself.

It is vital that you insert the wedge in this direction and at that angle or you will not get the results illustrated in the next two images. If you do choose to insert the wedge from the left lower corner, the results are reversed.

One must now pay good attention to how the isochromes (the colored rings) behave. In two, opposite, quadrants they will move outward while in the other quadrants they will move inwards. It is this movement that determines if the optic sign is + (positive) or - (negative).

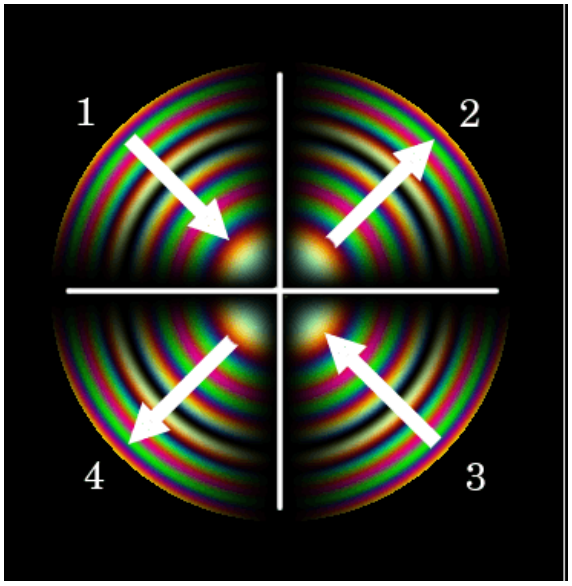


Figure 11.5.23

In this image (where the wedge is not shown for better illustration) the arrows in quadrant 2 and 4 move outwards and the isochromes will appear to do the same. This indicates a negative optic sign under the above conditions.
At the same time, the colored rings in the 1st and 3rd quadrants will move inward.

If you now move the wedge back from quadrant 1 to 3, the reverse is observed.

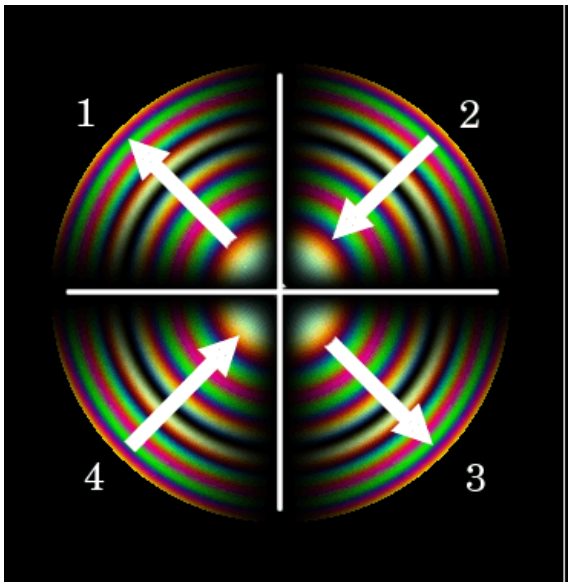


Figure 11.5.24

Here the isochromes in the 1st and 3rd quadrants will move out and the isochromes in the 2nd and 4th will move inward. This means that the stone is uniaxial +. A positive optic sign.

As with the negative optic sign image, when you move the quartz wedge in the opposite direction (back to quadrant 3), the movement of the isochromes is reversed.

Biaxial stones and the quartz wedge

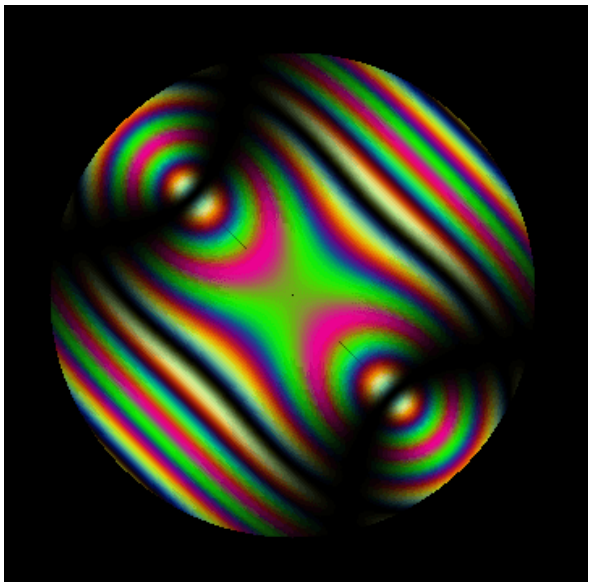


Figure 11.5.25

For biaxial stones, this technique becomes more difficult as one needs to find or the maximum curvature of the isogyres, or know where the 2 melatopes are.
The best approach is to turn the stone so it will show maximum curvature. This is done by laterally turning the stone so the isogyres are at 45° to the polarizer and analyzer as in this image.
The way one rotates the stone is not important. Here the interference pattern has the isogyres in the lower right and upper left, but they could be in the lower left and upper right as well. For right-handed people, this setup is probably best as one needs a steady hand to hover the quartz wedge.

It should be noted that this image is an ideal one (two isogyres seen), which is rarely the case.

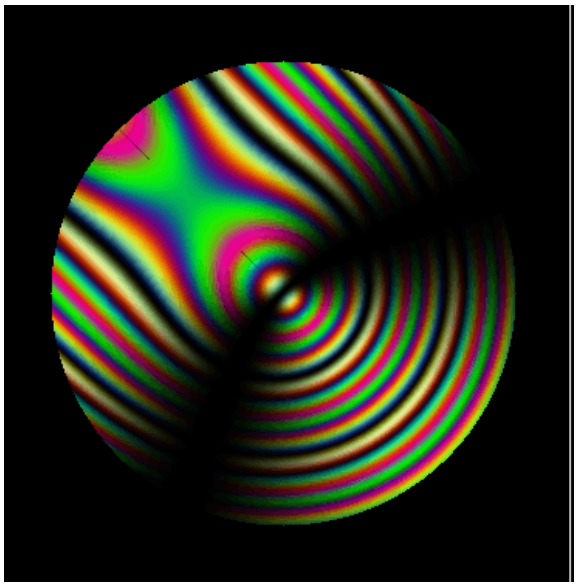


Figure 11.5.26

In most cases, you will see only one isogyre and that is all we need for the quartz wedge to work.
Here the curvature is easily seen and from that, we know where the other melatope is located.

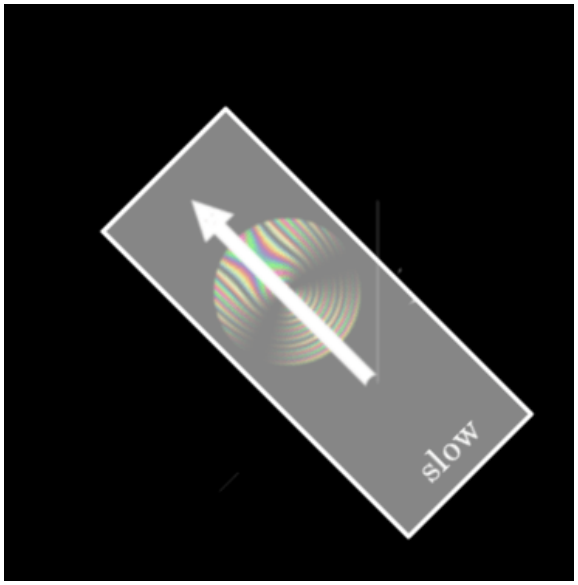


Figure 11.5.27

We now insert the simulated quartz wedge over the stone (with the conoscope in place) from the most concave side of the isogyre towards the most convex side and we need to observe how the isochromes behave.
Hover it back and forth over the interference pattern, but pay attention only to the change in the forward direction. That is the direction indicated by the arrow. The arrow is not actually on the wedge, it is there to show the direction of motion.

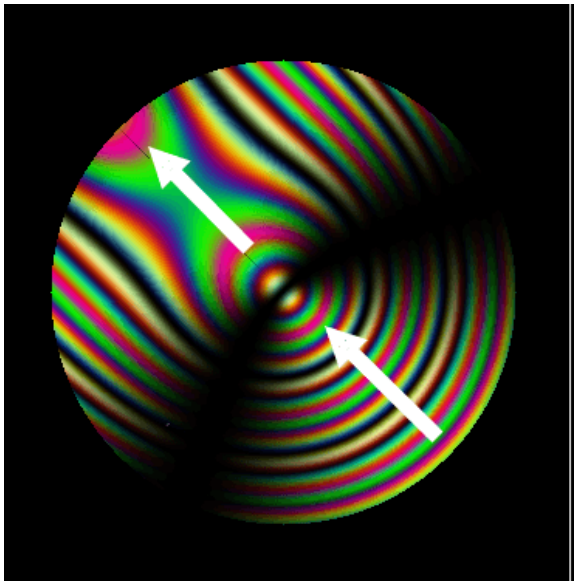


Figure 11.5.28

Here the wedge is removed for illustration.
If the isochromes move towards the other melatope (the one that is outside the view), the stone is biaxial with a positive optic sign.

When one hovers the wedge back and forth over the image, you will see the isochromes moving away and back. Pay attention only to the reaction of the forward motion.

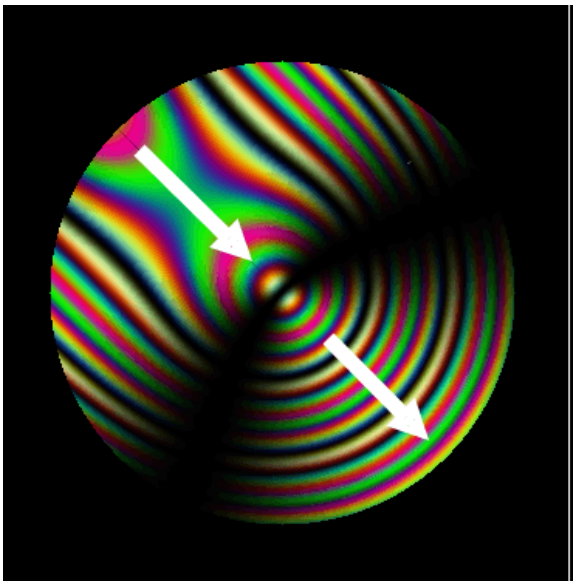


Figure 11.5.29

When the isochromes move away from the other, out of view, melatope, the stone is biaxial with a negative optic sign.

Another way of thinking could be:

- if the isochromes move along the direction of the movement of the quartz wedge, it indicates a positive optic sign
- if the isochromes move in opposite direction, the stone has a negative optic sign.

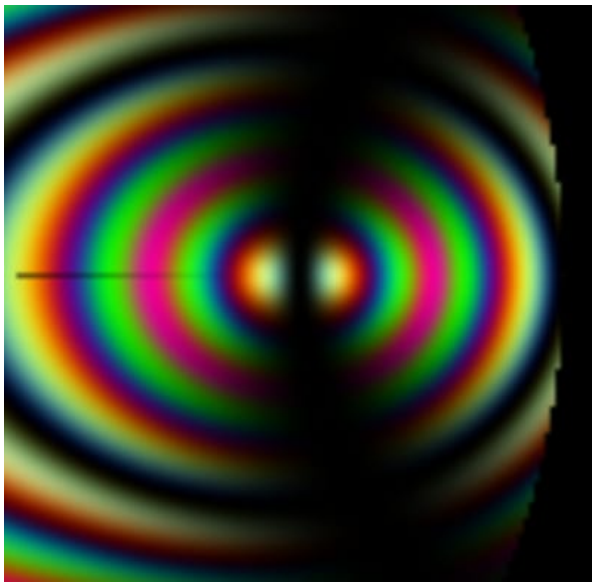


Figure 11.5.30

In some cases, you will see an image resembling what the GIA calls a "bowtie". It can be very hard to see what the concave and the convex sides of the isogyres are.
Although this indicates a biaxial optic character, the optic sign is very hard to obtain from this. This happens when the "2V" value is large (larger than 50°).

When you observe this image carefully, you will notice that the curve endpoints are at the right.

Tips and tricks

Honey

On page 64 of Ruby & Sapphire (1997), Richard Hughes shows a Thai/Cambodian sapphire with tiny droplets of methylene iodide to show the uniaxial interference pattern. The small drops act like tiny conoscopes and when applied correctly, you will have an extra hand free (the one that usually holds the conoscope). Hughes also suggested, through personal communication, the use of a small droplet of honey which works very well.
This technique works best with magnification as the obtained figures are very small.

Monochromatic light

With monochromatic lighting (such as a yellow sodium filter of your refractometer), the interference pattern may stand out more clearly.

Poor man's polarizing microscope

Buy two polarizing sheets (50 x 50 mm) and tape them in crossed position on your microscope. One just above the light source and the other just below the optics. This setup will give you a polariscope with the great benefit of magnification and you will find interference figures much easier to interpret.
Such a setup should not cost you more than USD 30.00 (probably less) if you already have a suitable gemological microscope.

Lucky woman's retardation plate

Florists usually have cellophane plastic in which they wrap their flowers. This cellophane may work as a quarter wave plate. The length of the roll is the fast ray, the cutting edge is the direction of the slow ray.
Simply cut a small piece from it and lay it on the polarizer (between the lower polarizing sheet and the stone) after you found the interference figure (at a 45° angle to the polarizer directions of course).
Other kinds of cellophane like ScotchTape may also work.

Immersion

Sometimes it is very hard to find interference figures. Place the stone is a shallow dish of water (or baby oil) and rotate the stone slowly in it. You will find the interference flashes more easily in certain circumstances.
The dish should be placed between the crossed polars.

Related topics

- Polarization
- Pleochroism
- Dichroscope

Sources

- *Guide to Affordable Gemology* (2001) - Dr. W. Wm. Hanneman, PH.D.
- Introduction to Optical Mineralogy *3rd edition (2003), Prof. W.D. Nesse*
- *Ruby & Sapphire* (1997) - Richard W. Hughes
- *Gem Identification Made Easy* 3rd edition (2006) - Antoinette Matlins, A.C. Bonanno
- *Edelsteinbestimmung* (1984) - Godehard Lenzen, Birgit Günther, Walter Grün ISBN 3-9800292-2-0

External links

- Conoscopy Illustrated (with a special acknowledgment for donating many of the conoscopic images)
- Identification of CVD Synthetic Diamond
- Patent for herapathite polarizers
- Patent description of PVA polarizers
- Virtual Polarizing Microscope

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11.06: Dichroscope

The dichroscope is a pocket-sized tool that can aid in the identification of gemstones. With plenty of experience, one could even positively identify some gemstones with the dichroscope alone (although confirmation tests should always be carried out).
This tool is used to inspect pleochroism in gemstones and to quickly separate some common stones from each other (such as ruby versus red garnet).

Basic

There are two types of dichroscopes on the market:

- calcite dichroscopes
- polarizing dichroscopes

In anisotropic gemstones, different colors are absorbed in different directions ("directional selective absorption") which causes the pleochroism that is observed with the dichroscope.

Calcite dichroscope

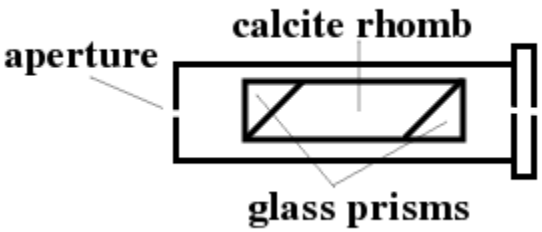


Figure 11.6.1**:** Calcite dichroscope

The calcite dichroscope is the preferred type of dichroscope used in gemology. It works because the calcite rhomb (Iceland spar) separates the polarized slow and fast ray emerging from the gemstone. If you look at the viewing end of the dichroscope, two small windows are seen.
A gemstone is placed in front of the aperture (slightly touching it) with a strong white light source (such as a penlight) directly behind the stone. Light enters through the aperture of the dichroscope. The pleochroism colors inside the gemstone are separated by the calcite rhomb. The glass prisms on either side of the rhomb are there to guide the light straight through the instrument.

Polarization dichroscope



Figure 11.6.2**:** *Two polarizers*

Pleochroism may also be observed with the use of a polarizing filter. The disadvantage is that one will only see one of the pleochroic colors at a time, making subtle changes of colors (shades) difficult to recognize. This can be overcome by placing two

polarizing filters close together, each orientated 90° to the other (one in North-South and the other in East-West position).

Although this kind of dichroscope is very economical, the results obtained by them are less clear than in the calcite ones. Stones with weak pleochroism will be hard to determine with this type of tool.

The London dichroscope is a popular brand.

Proper use and possible observations

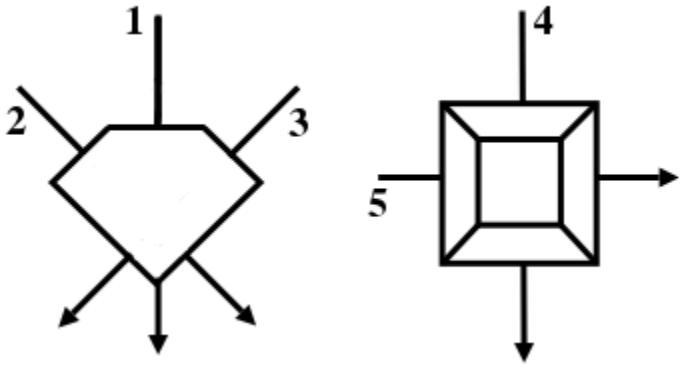


Figure 11.6.3***:*** *Inspection directions*

This part will focus on the calcite type dichroscope.

As with any other instrument, proper use will determine if you get accurate results.
The stone is held close to the aperture, even slightly touching it, with a strong allochromatic, white light source behind the stone. When one looks through the other end of the dichroscope, two small windows next to each other will be seen with a color in each of the windows. These colors may either be the same or different colors or different shades of colors.
Now turn the dichroscope slowly 180° between your fingers while keeping the stone in a fixed position and observe if the colors in the two windows are the same or if they differ.

This procedure should be repeated another 4 times from different angles.

1. through the table
2. through the crown facets
3. another direction through the crown facets
4. through the girdle
5. a different direction through the girdle

Of course for en-cabochon cut stones there are no tables or crown facets, but the inspection directions will be the same.

After making a mental image of the colors seen, there are three possibilities:

1. the colors in both windows remain the same in all directions

    the stone is isotropic (single refractive)

2. in total 2 colors are observed

    the stone is anisotropic uniaxial

3. in total 3 colors are seen

    the stone is anisotropic biaxial

In the images below (for isotropic, uniaxial and biaxial), two out of five observations are given.

Isotropic stones

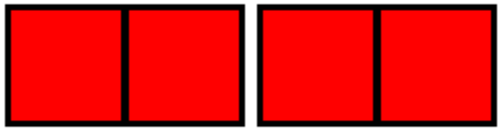


Figure 11.6.4

When the colors in both windows remain the same after 5 readings (2 of them are illustrated), the stone will be single refractive. In this image the colors are red, but they could be any color.
Not many colored stones are single refractive, so this will narrow down them quite a bit. There are, however, exceptions to the rule, such as heated citrine.

Uniaxial stones



Figure 11.6.5

Here 2 different colors are seen (red and orange) after 5 readings (two readings illustrated). This means the stone is uniaxial. Again, some exceptions to the rule exist. Low type zircon may show up as isotropic, while peridot (which is biaxial) may appear uniaxial.

These stones are considered "dichroic" (di = 2, chrom = colored).

Biaxial stones



Figure 11.6.6

When in total 3 colors (or shades of color) are seen after 5 readings, the stone is biaxial without exception.
Here the colors are red, orange and yellowish-green but they can be any colors or shades of the same color. Careful observations may even enable you to distinguish between natural tanzanite and heated tanzanite (zoisite).

When three colors are seen, we name it "trichroic" (tri = 3, chrom = colored).

Video Tutorial by Starla

Related Topic

- Pleochroism
- Polarization

Sources

- *Gem Identification Made easy* 3rd edition (2006) - A.C. Bonanno, Antoinette Matlins ISBN 0943763347
- Gemmology 3rd edition (2005) - Peter Read
- *Guide to Affordable Gemology* (2001) - Dr. W. Wm. Hanneman
- *Ruby & Sapphire* (1997) - Richard W. Hughes ISBN 0964509768

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11.07: Immersion Cell

Immersion cells are used to hold liquids in which a gemstone is placed. The main objectives are to reduce reflections so one can get a clearer view of the internal features inside the gem, or as a means to estimate the index of refraction of a gemstone through comparison.
Another use is to estimate the index of refraction of an inclusion in a gemstone (the gemstone itself will act as an immersion cell).

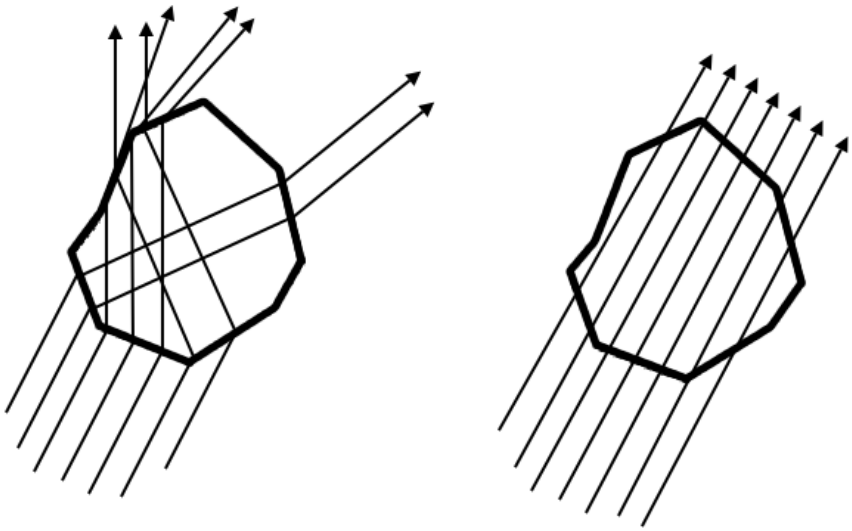


Figure 11.7.1***:*** *Refraction in a mineral (left) and the lack thereof when immersed in a liquid of equal index of refraction (right)*

There are circumstances when one can not use the gemological refractometer but still needs to know the approximate index of refraction of a gemstone. One method to accomplish this is to compare the gemstone with liquids of known index of refraction.

When light passes through a mineral the light will be refracted and reflected by the mineral, due to its higher index of refraction compared to air. This makes it possible for us to see the shape of the mineral (color disregarded). If we were to immerse the mineral in a clear liquid that has the same index of refraction as the mineral, the light will not bend inside the mineral, nor will there be any reflection. This causes the mineral to virtually disappear in the liquid.

The mineral will stand out against its surrounding medium at a certain amount, something we call "relief". The larger the difference in RI between the mineral and its surrounding, the higher its relief (the more clear it will stand out). Not only air or liquids can be used as the surrounding media, but a gemstone itself can also be that surrounding medium for an inclusion.

Refractometry

Anderson method

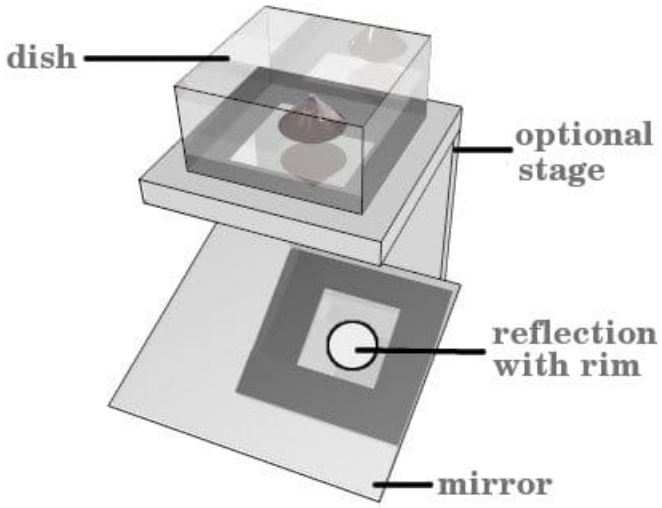


Figure 11.7.2***:*** *The Anderson immersion method of comparative refraction*

It is no secret that when you insert a drop of water in a glass filled with water, the drop will disappear. Although there are other reasons to why that happens, the focus now will be on the indices of refraction of the drop of water and the water in the glass.

As the drop has the same index of refraction as the water that is already in the glass, light will travel through it at the same apparent speed. This means that the drop of water will not bend the light more (or less) than the water it is now in (the water filled glass); the drop of water will disappear like magic.
If we were to drop a small glass bead (RI ~ 1.5) in the water (RI ~ 1.3) then there is a difference between the two indices of refraction and you will be able to see the glass bead in the water (although not as clearly as when it was in air (RI ~ 1). The glass bead will refract the light more than the surrounding water and this can be a very useful tool to determine the index of refraction of the glass or any other transparent material like a gemstone.

It should be clear by now that the closer the indices of refraction between the two media (liquid and gemstone), the more the stone will disappear when it is immersed in the liquid.

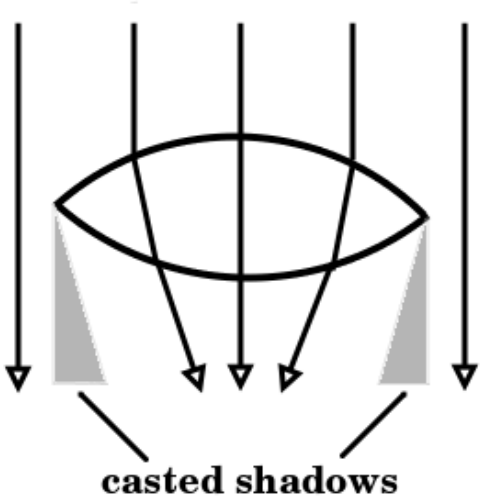


Figure 11.7.3***:*** *Illustration on the bending of light in a lens*

The famous gemologist B.W. Anderson devised a technique to make this visible with the aid of a series of comparative liquids. This technique is also named the "Anderson immersion method".
When a cut gemstone is placed table down inside a dish of water, the gem will act as a lens if the RI of the gem is larger than its environment (in this case water). Because of the difference in RI between the gemstone and the liquid (not just water) the gemstone will cast an inward shadow on the bottom of the glass. This shadow will be shown as a dark rim around the contour of the gemstone and the wider the rim, the larger the difference in indices of refraction between the stone and the liquid.
By placing a gemstone in a series of liquids with increasing (or decreasing) indices of refraction one can estimate the RI of the stone at hand. **The finer the rim, the closer the RI of the gemstone matches the RI of the liquid**.

When the stone has an index of refraction lower than that of the liquid, the result is reversed and one will see a bright rim around a darker core.

In order to observe this rim one only needs to insert a small mirror below the glass to redirect the image to the eye. You could, of course, lift the glass and observe from below, but that would require a ceiling lamp (and in time a physiotherapist).
As the light source needs to be above the immersion cell (the glass beaker) it is advisable that the light is diffused before falling on the mirror to reduce reflections from the light source. For this purpose, one can use an immersion cell with a frosted bottom or create the diffusion by a thin sheet of white toilet paper (peeled).



Figure 11.7.4***:*** *From left to right: casted rims (shadows) by a brilliant cut gemstone for decreasing RI difference between liquid and gemstone. From thick to fine*

The thickness of the rim should always be judged in relation to the size of the gemstone. In other words, the shadow is a percentage of the diameter of the gemstone.
When the immersion liquid is water it is obvious that a diamond will show a relatively thick rim, while a sapphire will cast a lesser thick one. If you put two of these stones next to each other in an immersion cell (a small diamond and a large sapphire), odds are that the absolute thicknesses of the casted shadows are the same or similar. For that reason, one needs to estimate the rims in relation to the diameter of the stones.

There are many liquids one can use and in cases that this technique needs to be applied to estimate the refractive index of a gemstone, it is best to immerse the stone in several liquids with progressive RI values. The RI of the stone will lie between the RI values of the liquids in which the stone casts the smallest shadows. In cases where there is no casted shadow, the RI of the liquid is equal to the RI of the gem (like the drop of water in a glass of water).

Plato method

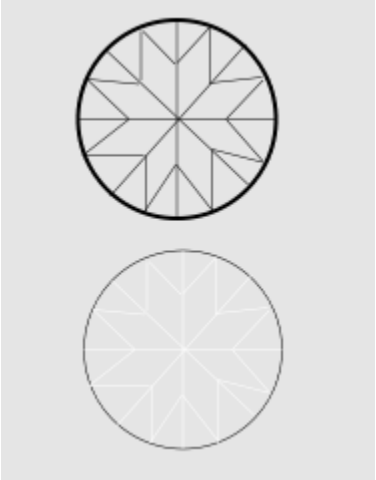


Figure 11.7.5***:*** *Idealized illustration of the "Becke lines" in the Plato immersion technique*

Like the Anderson immersion method, the Plato method (named after W. Plato) is an immersion technique to compare a gemstone with a liquid of known index of refraction. Both methods are derivations of the Becke line method that is most often used by mineralogists.
As with the Becke line technique, the Plato method requires magnification with a microscope.

A stone is immersed in a liquid of known index of refraction and the immersion dish is placed on the microscope stage with transmitted light. The diaphragm is closed to approximate the diameter of the stone and the focus of the lenses is just above the stone. When the facets edges of the stone appear dark, the index of refraction of the liquid is higher than that of the stone. On focusing inside the stone, the facet edges start to appear bright.

When the reverse happens (bright on focus above the stone and dark when the focus is lowered into the stone), the stone has a lower index of refraction compared to the liquid. When the RI of the liquid is equal (or almost equal) to the RI of the stone, the edges will remain bright.

Although this technique is fairly straightforward, it does require some practice with stones and liquids of known indices of refraction. Especially trying to focus just above the stone can be cumbersome as the image of the stone is very blurry at that point. On lowering the focus inside the stone more facet edges will start to appear that can provide the information one is searching for.

This technique should not be confused with the color concentration on facet edges in some diffused stones as sapphire.

References

- *Guide to Affordable Gemology* (2001) - Dr. W. Wm. Hanneman
- Gemmology 3rd edition (2005) - Peter Read
- Gems Their Sources, Descriptions and Identification *4th Edition (1990) - Robert Webster (6th ed.)*
- Introduction to Optical Mineralogy *3rd edition (2003), Prof. W.D. Nesse*

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11.08: Color Filters

Color filters have many uses in gemology. The Chelsea Colour Filter™ (CF) is the most prominent of them.
While the CF is the most used, other filters can serve for a variety of applications. Among those are diffused colored plates used in conjunction with a microscope to inspect sapphires, narrow bandwidth filters to determine dispersion, and blue, red or yellow filters to examine fluorescence in gemstones.

Some people regard the CF as a primary tool, yet all modern gemology writers disagree with that statement. It can, however, give clues to the identity of a gemstone when used as an additional (secondary) tool. One can never rely on observations with any color filter alone.

Most color filters show their real power when inspecting parcels of gemstones. When one examines, for instance, a parcel of blue sapphires with a CF, some stones would stand out bright red from the rest of the lot. One should immediately be very suspicious of those appearing red when viewed through a CF, as this is not a typical observation for sapphire.
As these filters are highly portable, they are used on locations where one could not take larger gemological equipment. Gem/mineral shows and flea markets are some of those locations.
At best, the filters are there to alert suspicion. They tell you little about the identity of the gemstone.

Basic

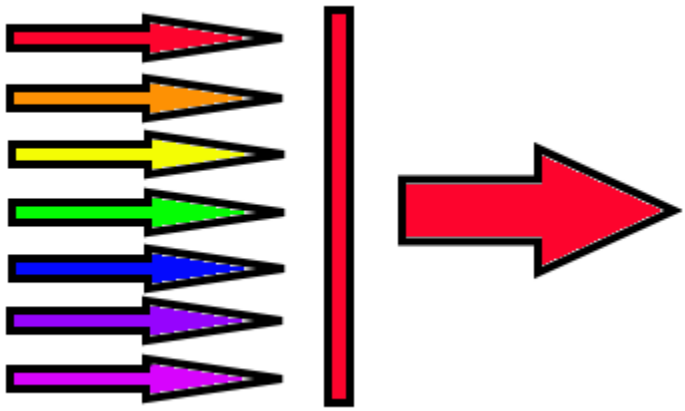


Figure 11.8.1

All color filters work on the same principle: they absorb certain wavelengths of light, letting only a portion of the visible part of the electromagnetic spectrum pass through.

In the image on the right, all colors of the visible range except red are absorbed (blocked) by a color filter, thus letting only red light pass through. This lets us control light, which can be very useful when inspecting gemstones.

Proper use of colored filters

When used as a stand-alone instrument (not with a refractometer or microscope), the filters should be held close to the eye as with a hand lens. A strong allochromatic light source should be used to get as much light into the stone as possible. As with the spectroscope, the stone is best observed in reflected light with the stone table down on a non-reflective background.
Do not use fluorescent lightning as these lights contain little to no red parts of the electromagnetic spectrum.

Chelsea Colour Filter™

This filter was developed in the 1930's by Anderson and Payne in conjunction with the gemology class at Chelsea College in London, UK. The CF (as it is often abbreviated for "Chelsea Filter") lets only the red and yellow-green portions of white light pass through it.

Its original use was as an emerald filter for distinguishing between natural emerald and its look-a-likes since most emeralds would appear red through the filter. The chromium content of emerald shows as the red color seen through the filter, but chromium is now widely available in its synthetic counterparts (although often the synthetic emeralds may show a more vivid red through the filter). So with the coming of synthetic emeralds, the CF's primary use as an emerald filter was no longer valid. Besides, some natural emeralds do not appear red through the filter at all.

However, it proved to be useful in other circumstances. With a few exceptions (such as rare natural cobalt colored spinel), hardly any gemstone is colored by cobalt but most synthetic spinels and blue glasses are.
These cobalt colored stones stand out bright red when viewed under the CF. Some natural blue sapphire may have traces of chromium, making them appear reddish as well.
Natural colored jadeite and dyed jadeite may also be separated by the same means.

Many gemstones have typical reactions to the CF and long lists are available in most standard gemological textbooks. The colors observed are usually red or green, various shades of those colors, or no reaction at all. Usually, the deeper the color of the stone, the more vivid the reaction.

The many exceptions to the rule make it a tool of "early warning".

Emerald Filters

These filters, also known as "Hanneman-Hodgkinson Synthetic Emerald Filters", are additional tools to the Chelsea Colour Filters. When a gemstone is identified as emerald (natural or synthetic) by other means of identification, the stone is first examined through a CF. If the stone appears red, then the Emerald Filter is used. If the emerald then appears red through this filter as well, it is synthetic. The motto is "red red, drop dead!".

The Emerald Filter is shipped with a "support filter" and is used in cases when the emerald appears green through the CF.

Tanzanite Filter

This filter was created by Dr. Hanneman to discriminate between tanzanite and its simulants (such as synthetic forsterite). It is made of two filters: a color filter (Hanneman aquamarine filter) and a dichroscope (London dichroscope type with two polarizing sheets).
The stone is inspected first with the color filter part of the device and then viewed through the dichroscope part. Tanzanite will give you a unique combination that is not observed in its simulants: pinkish-orange through the color filter and purplish-pink/blue through the dichroscope side.

Other color filters

The Ruby Filter, Aquamarine Filter, and Jade Filter, as well as some other filters, work on the same principle. These filters may be useful for your particular needs, but like the others, they are not primary tools.

Richard W. Hughes introduced blue and green filters in conjunction with an immersion cell to inspect color zoning in corundum. When inspecting a yellow sapphire for color zoning under the microscope, you would immerse the stone in an immersion cell with di-iodomethane (methylene iodide). As the yellow of the light, the yellow of the immersion fluid and the yellow of the gem are not the best ingredients when trying to spot yellow zoning, a blue filter is placed just above the illumination to counteract the yellow in the light source, which would enable you to see color zoning much easier.
For yellow and orange stones, a blue filter is used. For red stones, a green filter is used.

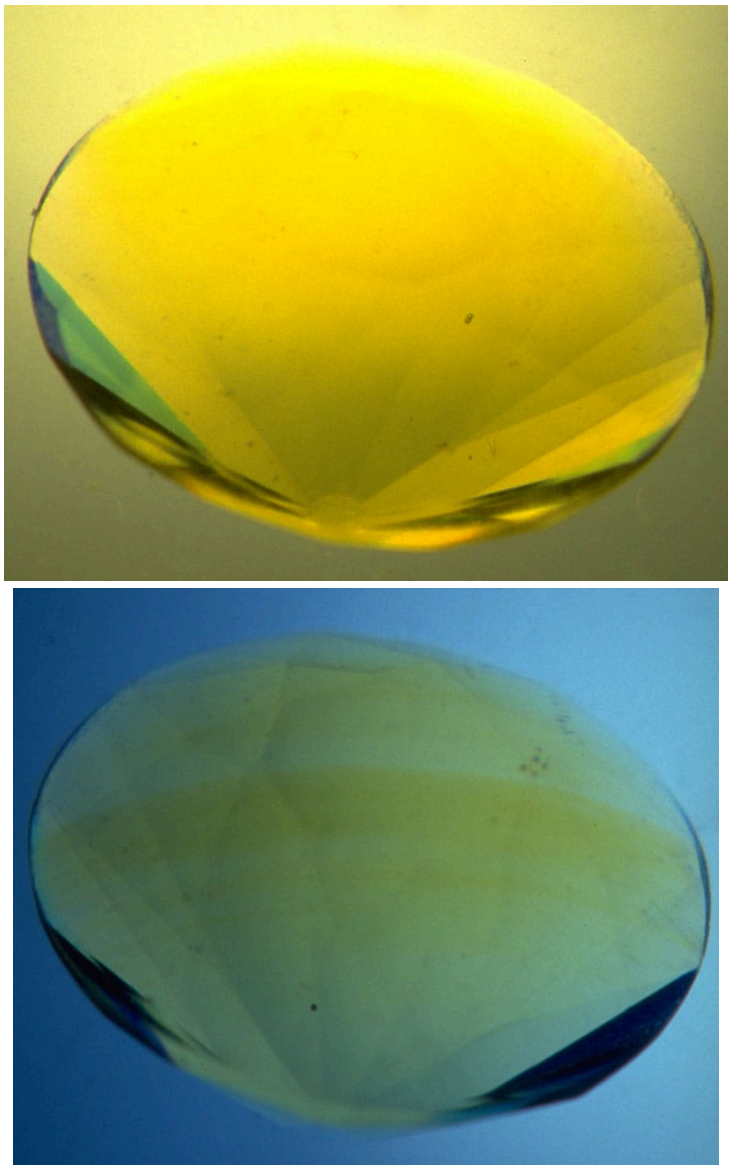


Figure 11.8.2

At left, a Verneuil synthetic yellow sapphire in di-iodomethane. At right, the same stone with a frosted blue filter below the immersion cell. The curved growth lines are now far easier to see.

Crossed filters technique

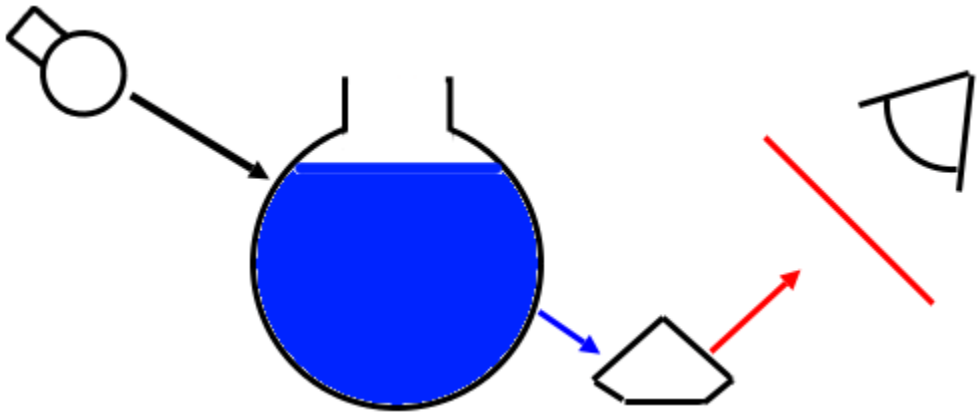


Figure 11.8.3***:*** *Copper sulfate solution in a flask and a red filter*

The "crossed filters" technique should not be confused with "crossed polars" or "crossed polaroids" as the latter two have to do with polarization, not luminescence.
A flask is filled with hydrous copper sulfate and white light is passed through the solution. The exiting light will be blue. During the illumination of the gemstone with this blue light, a red filter is placed between the eye of the observer and the stone. If the stone appears red when viewed through the red filter, this is clear proof that the stone is fluorescent in daylight.
The activator in the gem which causes this is the presence of chromium (Cr) in the crystal lattice and this effect is seen predominantly in ruby, alexandrite, emerald, red spinel, and pink topaz. It should be noted that iron (Fe) can greatly diminish or completely eliminate this fluorescence effect. As synthetic materials usually carry more Cr and little to no Fe, this glowing of red light is generally more intense than in their natural counterparts.

The hassle of carrying hydrous copper sulfate is luckily eliminated by the invention of blue LED pocket (or keychain) torches that may be purchased for just a few USD at the local hardware shop. One can use a sheet of red selenium glass as the red filter, or even a Chelsea Colour Filter. Other sheets, like plastics, could also serve as crossed filters.
A sheet of blue material in front of one's light source can mimic the copper sulfate solution and/or the LED torch.

Using the same light source in conjunction with a spectroscope, one can then easily distinguish between ruby and red spinel.

Related Topics

- Luminescence
- Spectroscope

References

- Gemmology 3rd edition (2005) - Peter Read
- *Gem Identification Made Easy* 3rd edition (2006) - A. C. Bonanno, Antoinette Matlins ISBN 0943763347
- *Crossed Filters revisited* - D. B. Hoover and B. Williams, The Journal of Gemmology, July/October 2005

External Links

- Proletarian Gemology: The blue filter

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11.09: Microscope

Next to the refractometer and the loupe, the microscope is probably the most-used instrument among gemologists. Its obvious use is for magnification of internal and external features of gemstones, giving the gemologist extra information about the identity and quality of the stone.

Basic

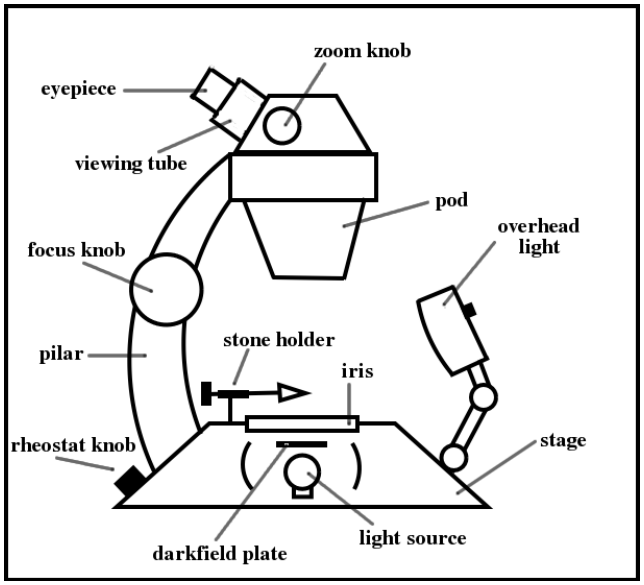


Figure 11.9.1

Gemologists usually use binocular microscopes with zoom capabilities ranging from 10 to 90 times magnification. In most circumstances, a magnification of 45x is sufficient for day-to-day operation. These binocular zoom microscopes are the most expensive pieces of identification equipment used in the standard gemological laboratory.
When handled with care, they will last a lifetime and are well worth the investment.

Some binocular microscopes do not have a zoom feature and these are far less expensive. Typically, the magnification ranges go from 10 to 30 to 60 times (in steps). For these steps of magnification, the oculars (eyepieces) need to be exchanged.

A good gemological microscope should at least be equipped with a light field and a dark field, an overhead illumination and preferably an adjustable iris. An integrated stone holder is a good choice as well.

Types of illumination

Most gemological microscopes provide a whole range of illumination and associated techniques which all have their characteristic uses.

Pinpoint-source illumination

Good gemological microscopes will have an adjustable iris diaphragm that will enable you to reduce the light source by closing the diaphragm to just a small pinpoint opening.

This makes it easier to spot curved striae and other structures inside the gemstone.

Opening the diaphragm to just less than the diameter of the gemstone works as a "shadowing technique".

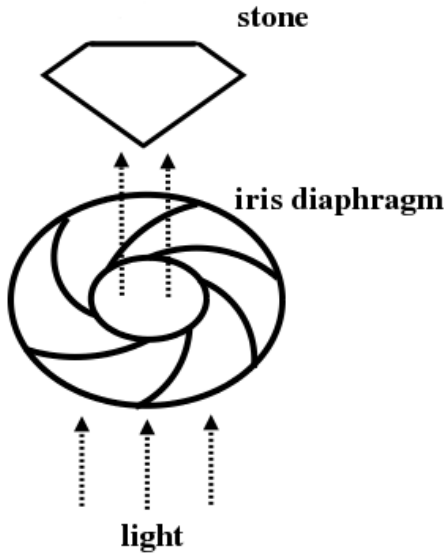


Figure 11.9.2***:*** *Pinpoint-source illumination*

Light field illumination

With the light entering directly from below, low relief inclusions and curved striae are seen as dark objects against a bright background. This is often used with pinpoint illumination.

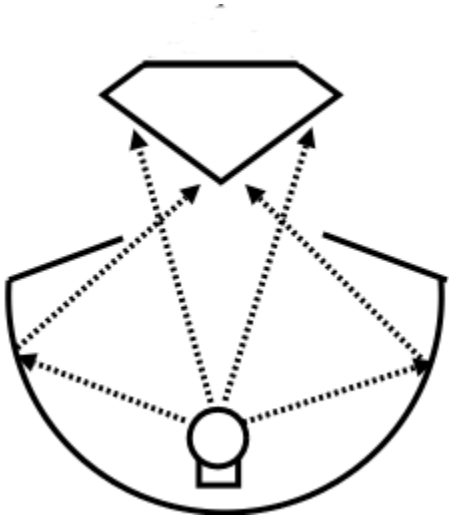


Figure 11.9.3***:*** *Light field illumination*

Dark field illumination

Dark field illumination is probably the most-used type of illumination in gemology.
A dark plate covers the bright light illumination, causing the light to be reflected before reaching the stone. Inclusions will stand out bright against a black background when using this technique.

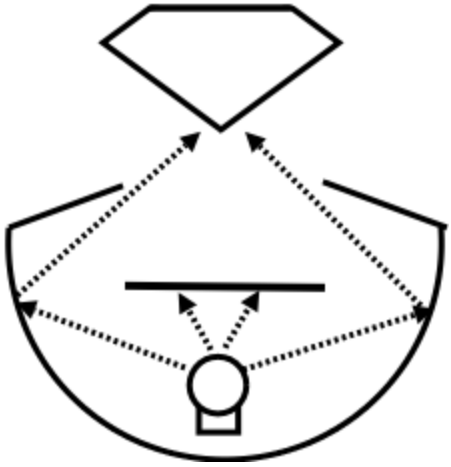


Figure 11.9.4***:*** *Dark field illumination*

Overhead illumination

Overhead lighting usually involves fluorescent lighting and is used to inspect the external features of gemstones, such as polishing marks, pitting and other marks that are found on the surfaces of gemstones.

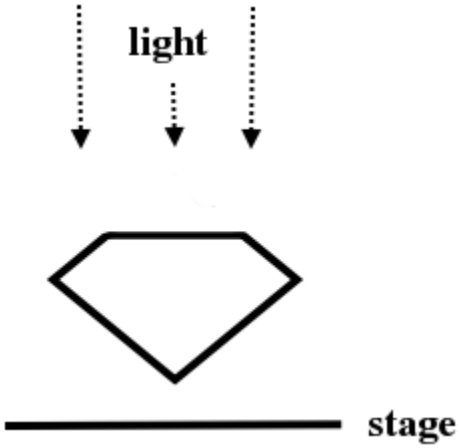


Figure 11.9.5***:*** *Overhead illumination*

Diffused illumination

When a sheet of tissue paper or any other diffusing object is placed over the bright light illumination, the light will become scattered and softened. This makes it easier to observe broad color zoning and color banding.
A white frosted plastic or glass plate is best for this technique. A blue diffusor may come in handy when looking at yellow to orange stones, as the blue will counteract the yellowish hue in most light sources.

When you use tissue paper, make sure the tissue doesn't get heated by the light as that is a potential fire hazard.

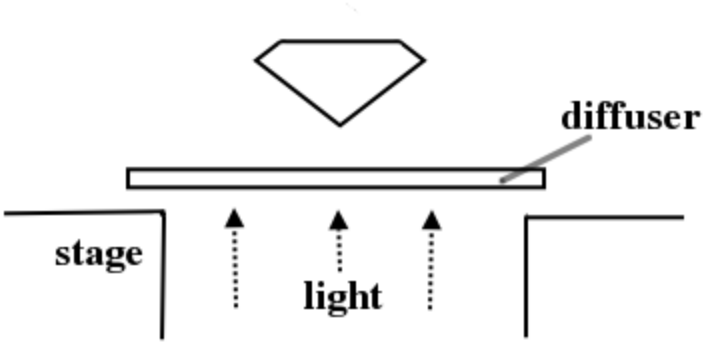


Figure 11.9.6***:*** *Diffused illumination*

Horizontal illumination

Horizontal illumination (or penlight illumination) is used to direct horizontal light into the stone. This causes gas bubbles and small inclusions to stand out brightly.

A fiber optic light could also be used for this.

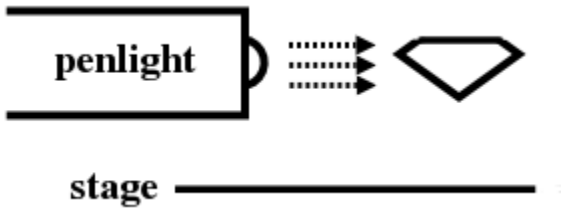


Figure 11.9.7***:*** *Horizontal illumination*

Polarized illumination

With polarization filters in place, the microscope becomes a polarizing microscope (a polariscope with the benefit of magnification). This is very useful when looking at twin planes, strain, pleochroism, and for determining optic character (and sign) and for distinguishing synthetic from natural Quartz.

A very cost-effective setup (about USD 10) involves a polarizer placed over the iris and an analyzer sticky-taped under the pod.

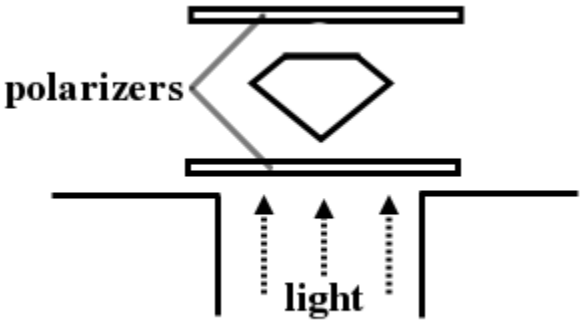


Figure 11.9.8***:*** *Polarized illumination*

Oblique illumination

Fiber optic illumination has the big advantage of letting you direct and concentrate light where it is most needed to view inside the gemstone.

Generally, a 150-watt fan-cooled illuminator is used as the lighting source. These light sources are highly portable and can be used for other instruments (like the refractometer and the spectroscope) as well. A highly suggested add-on for your laboratory.

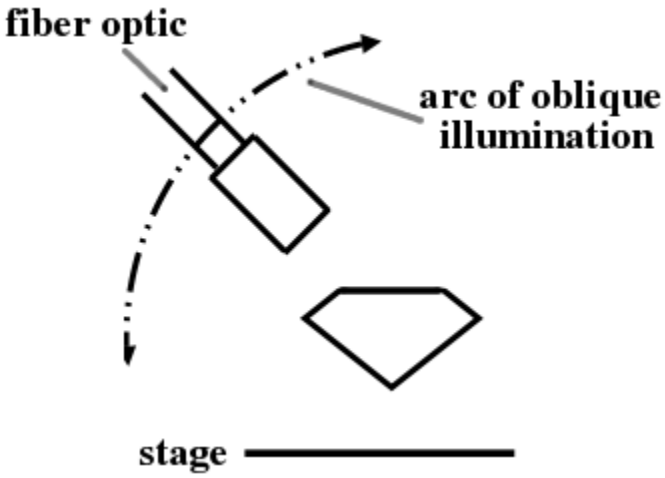


Figure 11.9.9***:*** *Oblique illumination*

Shadowing technique

An opaque, thin object (like a credit card) is inserted in the light path. This introduced object causes diffraction on the light beam and the 3-dimensional image of inclusions is greatly increased.
Growth structures such as twinning and curved striae are much more easily observed with this technique.

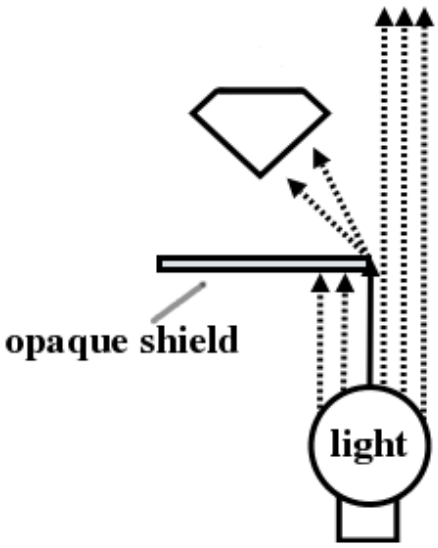


Figure 11.9.10***:*** *Shadowing technique*

Sources

- *Mark VII Gemolite Microscope Owner's manual* - GIA Gemological Instruments
- *Ruby & Sapphire* (1997) - Richard W. Hughes
- Gemmology 3rd edition (2005) - Peter Read

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11.10: Hydrostatic Balance

The hydrostatic balance is used to determine the specific gravity of a gemstone. Although it is a fairly simple apparatus to operate, it can be time-consuming. One must put the results into a calculation, something not all gemologists enjoy doing.
A specific gravity reading is considered a "primary test" in gemology yet, due to the time this method can consume, it is often regarded as a method of last resort in a standard gemological setup.

Basic

Main article: Specific Gravity

Specific gravity (SG) is a constant ratio of an object's weight compared to an equal volume of water. When an object is totally immersed in water, it will experience an upward thrust that is equal to the volume of water which is displaced by the object. This will make the object appear lighter in water.
The first to observe this was Archimedes while investigating a possible fraud concerning a crown made for King Hiero of Syracuse (present-day Sicily).

Archimedes and Archimedes' Principle

When King Hiero commissioned a new gold crown, a certain volume of gold was provided to a goldsmith who manufactured the crown to the liking of the king. Soon after, rumors circulated that the goldsmith may have been fraudulent, that he may have added silver to the gold, making a nice profit for himself on the side.
King Hiero asked Archimedes to investigate. One day while at the public baths, Archimedes noticed how his body mass caused the water in the bath to overflow. In his excitement over finding a possible answer to the problem, he ran home naked, shouting "Eureka!" (“I've found it!”).

Archimedes then immersed equal weights of gold and silver in water and, by observing the amount of water that was displaced, he realized that the mass of gold displaced less water than the silver. He then immersed the crown. Through a series of calculations he was able to determine how much gold and silver was used to create the crown. The fraud was detected. That was the first time in history the concept of SG was used.

Archimedes' Principle (or the Law of Buoyancy) states that: the upward force on an immersed object is equal to the weight of the displaced fluid.

Types of hydrostatic balances

In gemology, 4 different types of hydrostatic balances are used.

- The two-pan scales
- The one-pan scales
- Spring balances
- Direct reading scales

Two-pan scales

The two-pan scales are the most time-consuming scales to use though some jewelry stores still have them. But they are rarely used for determining SG of stones, mostly because the counterweights are generally too big to be of any help. Besides, they really need to be calibrated every few years.

Even so, the principle of the two-pan scale is very useful for explaining the hydrostatic balance.

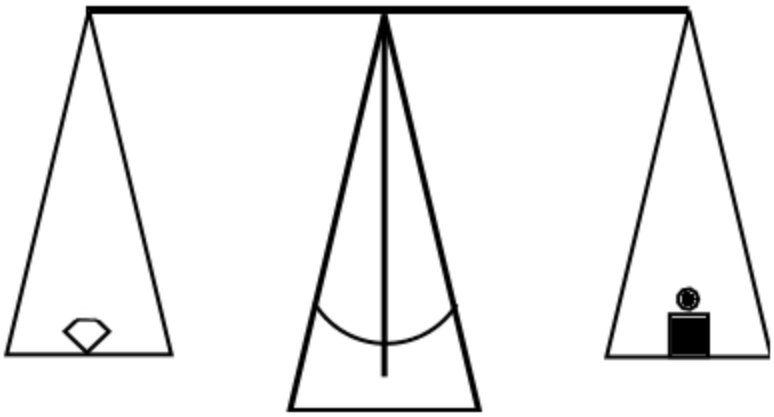


Figure 11.10.1

A gemstone is placed on the left pan of the balance. Weights are placed on the right pan until the balance "zeros out". When the balance is equal, the total of the weights on the right pan is read and that represents the weight of the stone in air.

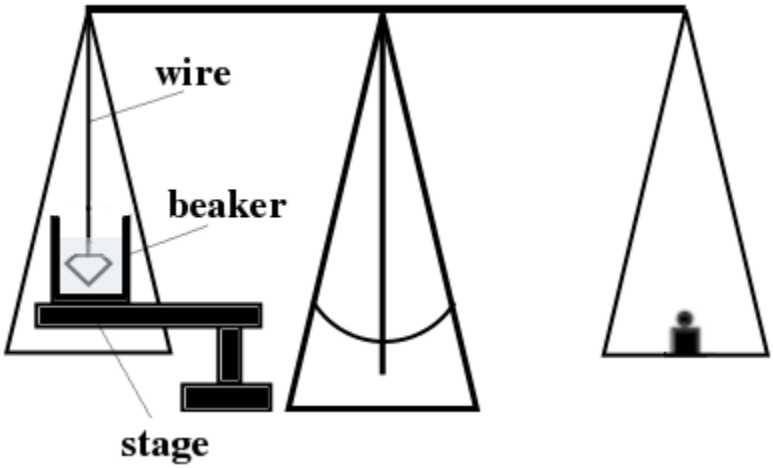


Figure 11.10.2

Then a freestanding stage with a beaker filled with water is introduced. After that, a thin coil wire basket is hung on the left side of the balance with the basket totally immersed in the water. At this point, the balance should be in complete balance by adding a small weight that is equal to the weight of the basket.
The stone is placed in the thin coil wire basket and then immersed in the water. Again, counterweights are placed on the right pan as before and the result of added weights will be the weight of the gemstone in water.
The wire basket should be of a material that is not water absorbent to avoid false readings. One should also take care that air bubbles around the basket and stone do not influence the readings, since air bubbles tend to rise upwards and can add to the upward thrust.
To avoid surface tension, a small droplet of detergent is added to the water.

After taking both the weight in air and the weight in water, the following calculation needs to be carried out.

$$SG = \frac{weight\ of\ stone\ in\ air}{weight\ of\ stone\ in\ air\ -\ weight\ of\ stone\ in\ water} \tag{11.10.1}$$

Single-pan scales

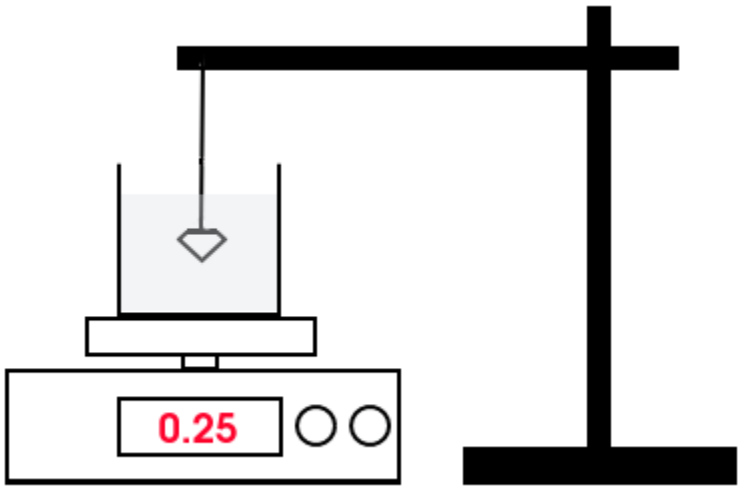


Figure 11.10.3

Most gemological scales are of this type. They can be either analog or digital and they come in various sizes and in every price range. For our purposes, it is best to get a carat scale as opposed to a gram scale. A gram scale may serve very well if it has a high precision that can read 0.01 grams, which is equivalent to 0.05 carat. These digital scales are very economical, under USD 100.

Various hydrostatic setups can be used with digital scales. One could use a bridge on which the glass beaker is placed, with a coil wire that is placed directly on the scale (see video below). Or the beaker can be placed directly on the scale with the stone hanging from a wire that is attached to a stage (as illustrated on the right), but note that in this last setup, the standard gravity is equal to the weight of the stone divided by the weight that is read when the stone is hung in water, and also the wire has to be as thin as possible.

Spring balances

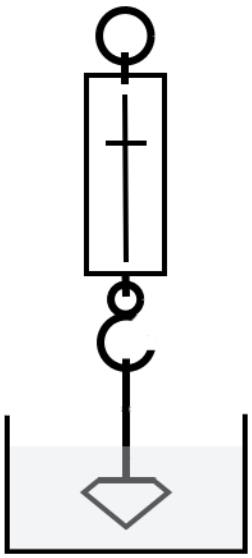


Figure 11.10.4

This type of hydrostatic weighing can come in handy when handling large pieces of rough that are heavier than your usual balance can handle.
Spring balances are relatively inexpensive and can vary widely in accuracy. Before weighing the stone, one must, of course, weigh the part of the balance that is immersed into the water so that can be deducted. As usual, the stone is first weighed in air and then it is weighed in water.
The larger the rough and the higher the accuracy of the balance, the more precise your measurements will be.

A spring balance is usually used in the field just like a recreational fisherman would use it to weigh a fish.

Direct reading scales

These are also known as "Hanneman direct reading specific gravity balances" in honor of the one who reinvented (or at least popularized) this old wheel – Dr. W. Wm. Hanneman. It cleverly makes use of both Archimedes' Principle and Archimedes' Lever. It is an adoption of "The little balance" by Galileo Galilei.
Their operation is like the weighing scales you see at a physician's or weight-watchers' office, where a weight is shuffled from one end to the other.

A direct reading scale can be constructed with little effort from household materials and has an accuracy of about 0.002 carat. Instead of having to go through the pain of calculations, this scale will give you an immediate read on the SG of the gemstone. The full description on its construction is given in Dr. Hanneman's "Guide to Affordable Gemology".

Legal requirements

Some countries impose strict regulations on the use of weighing scales when used in a commercial environment. This means that the scale needs to be labeled with a document (sticker) proving the scale is calibrated to legal requirements.
These scales are in general much more expensive.

In the European Union, this is regulated under the Non Automatic Weighing Instruments Directive (NAWI).
For Canada, this is regulated through the Canadian Measurement Act.

Related topics

- Specific Gravity
- Heavy Liquids

Sources

- Gemmology 3rd edition (2005) - Peter Read
- *Guide to Affordable Gemology* (2001) - Dr. W. Wm. Hanneman

External links

- Archimedes' discovery
- Archimedes' discovery investigated
- Galileo Galilei's Little Balance described

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11.11: Heavy Liquids

Heavy liquids are substances in liquid form that have a known Specific gravity (SG) and are used as a means of quick separation of stones with similar appearance. In general, these liquids are highly toxic and precautions should be taken when used.

Basic

Heavy liquids are stored in the dark to prevent light from influencing their physical properties. The containers need to be stored closed with a stopper to prevent evaporation.



Figure 11.11.1

Safety warning

Before using heavy liquids, it must be stressed that one should avoid all contact with the skin and that they are non-potable. Always use tweezers to insert the gemstones and, if liquid comes in contact with the skin, you should wash thoroughly. When in contact with eyes, you should rinse your eyes with streaming water and contact your medical doctor immediately.

Always use heavy liquids in a well-ventilated environment. They should be kept away from children and pets.

Use of heavy liquids

The use of heavy liquids is fairly straightforward. When a stone is immersed into the liquid, it will either float, suspend, or sink.

When the SG of the liquid is known, take the gemstone in your tweezers and gently lower the stone in the liquid. Observe the stone while looking through the side of the bottle and take the stone out again with your tweezers.
Carefully rinse the stone and tweezers under streaming water (you might want to take precautions to not let the stone go down the drain with the water), or you could rinse it in a large beaker filled with clean water.

After your observations, you should be able to tell if the stone's SG is higher, lower or equal to the heavy liquid used.

- When the stone floats in the liquid, it will have an SG lower than the liquid.
- When the stone is suspended in the liquid, SG will be equal to the liquid.
- When the stone sinks, it will have a higher SG than the liquid.



Figure 11.11.2***:*** *Float*



Figure 11.11.3***:*** *Suspend*



Figure 11.11.4***:*** *Sink*

One can also observe to which degree a stone will sink or float after suspending it in the liquid.
For instance, when the stone sinks rapidly it will have a far greater SG than the liquid.

Types of heavy liquids

In gemology, generally 4 heavy liquids are used.

- Methylene Iodide - SG = 3.33
- Methylene Iodide diluted with Toluol - SG = 3.05
- Bromoform - SG = 2.85
- Bromoform diluted with Toluol - SG = 2.65

In addition to these four, there is Clerici Solution with a SG of 4.2, used in laboratories. This solution can be diluted with water to lower its SG, such as SG = 4 or SG = 3.52 for instance. This solution is extremely toxic and should only be used in a well-equipped laboratory with additional safety precautions such as an acid chamber.
Dr. W. Wm. Hanneman suggests the use of Sodium Polytungstate as a non-toxic alternative for most heavy liquids.

Aside from these, there is also a water/salt solution for identifying Amber.

Methylene Iodide

Methylene Iodide (CH_2I_2) is also named di-idiomethane and has a SG of about 3.33. Yellow Topaz (3.5) will sink in this liquid while Citrine (2.65) will float.

Methylene Iodide diluted with Toluol

Methylene Iodide diluted with Toluol has an SG of 3.05. This liquid can easily separate Tourmaline (3.05) from Topaz (3.5) because Tourmaline will suspend in this liquid while Topaz will sink.

Bromoform

Undiluted Bromoform has a SG of 2.85 and can be calibrated to a lower SG with the addition of Toluol.

Bromoform diluted with Toluol

Diluted Bromoform with an SG of 2.65 is the indicator for Quartz.

Clerici Solution

This highly toxic Thallium-based liquid has a SG of 4.2 and can be diluted with water to calibrate it for Corundum (4) or Diamond (3.52).

Sodium Polytungstate

Sodium Polytungstate is a commercial, non-toxic and odor free alternative for most heavy liquids. It is sold as a white powder to which water is added to form a solution. The upper value of the saturation is 3.10. By adding water, it can go down to whatever SG is preferred.

Lithium Metatungstate (LMT)

Another common heavy liquid is Lithium Metatungstate (LMT). It is sold at 2.95 specific gravity and can be diluted with distilled water down to 1.0 Specific gravity. LMT is safe to use and it is the most affordable inorganic heavy liquid on the market. Visit LMTLiquid.com for more information.

Saline Solution

When 7 grams of ordinary salt (Halite) is saturated in 50cc of water, a solution with a density of 1.12 is created. This permits Amber (SG = 1.08) to float in it while some simulants (most of which - but not all - are plastics) sink.

Calibration of heavy liquids

Since evaporation, temperatures and light conditions may affect the SG of the liquids, it is recommended to have calibration stones at hand so one can periodically adjust the solutions. Changes in temperatures especially can highly influence the calibration.
If the calibration stone suspends in the liquid it will be up-to-date, otherwise one should adjust the solution.

Generally, one calibrates a heavy liquid by dropping a calibration stone slowly into a liquid and diluting it drop by drop until the stone of known SG suspends in it.

Sources

- Gemmology 3rd edition (2005) - Peter Read
- *Guide to Affordable Gemology* (2001) - Dr. W. Wm. Hanneman, Ph.D.
- *Journal of Gemmology*, Vol.22, No. 6 (April 1991) - Gem-A
- Gems Their Sources, Descriptions and Identification *4th Edition (1990) - Robert Webster (6th ed.)*
- *Gem-A Foundation notes* - Gem-A

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12: INCLUSIONS

12.1: Inclusions

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12.1: Inclusions

Basic

Inclusions can be generally defined as a foreign body, liquid, gaseous, solid, alone or in combination enclosed in the mass of a mineral. In gemology, we will expand that to also include cleavage cracks, fractures, color zoning, growth lines and included crystals of the same composition. Almost all gem materials, whether naturally occurring or man-made, will contain inclusions.
Some may be quite attractive or invisible to the eye. Others may be large and ugly and lessen a gem's value. Certain inclusions, like byssolite in demantoid garnet can increase a gem's value.
Do not confuse the word "inclusion" with the often derogatory terms "imperfections" or "flaws" that have been used in the diamond trade. These descriptions should not be used when referring to inclusions in colored gems.

Types of Inclusions

Inclusions can be classified under two headings. First, as a function of the material that composes them, such as solid, liquid or gaseous. Secondly, when they were formed relative to the formation of the crystal that encloses them. One can simply refer to them as pre-existing, contemporary or post-formed.

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13: GEMSTONE TREATMENTS AND ENHANCEMENTS

13.1: Gemstone Treatments
13.2: Heat Treatment

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13.1: Gemstone Treatments

A Brief History of Gemstone Treatments

The treatment and enhancement of gemstones has existed for hundreds and hundreds of years. The first documentation of treatments was presented by Pliny the Elder. And, 2000 years later, many of these treatments are still being used today! Some enhancements improve on nature, cannot be detected and are permanent; this provides the gem market with a larger supply of beautiful gemstones. Other treatments produce dramatic changes in the gemstone itself or it's clarity; the irradiation and heating of colorless topaz that permanently transforms it into blue topaz is an excellent example. A few treatments are less stable and should be avoided by the knowledgeable buyer. Following is a description of some common treatments. This is just the tip of the iceberg. Please refer to the recommended reading list at the bottom of the page for further information.

In the past, treatments of gemstones were usually done by the cutter. The lapidary wanted the value of the finished product to be as high as possible. Today, there are centers, such as Bangkok in Thailand where there are facilities that specialize in the treatment of both rough and fashioned gems. The heat treatment of corundum (rubies and sapphires) is an excellent example. The heat treatments of corundum (both simple heating and heating with a flux, such as beryllium) are often done before cutting, and may not be disclosed to the lapidary before cutting is done.

Treatments and Pricing

There are some gemstones that would not even exist if it were not for treatments. The abundance of citrine, in shades of yellow, gold and orange is the result of heat treating amethyst. Naturally occurring citrine is quite rare in nature. If it was not for treatments the stone would be far more expensive than it is! Tanzanite in shades of violet and blue depends on heat treatment to produce enough supply to meet the demands of the public. Pink topaz is another example of a gem that would not be available without heat treatment. Not only are these treatments acceptable, but they are also necessary to keep these products affordable and available. Recent demand for unheated sapphires and rubies has caused a price increase of as much as 50%-100% for unheated material. Does this mean that the untreated gem is more beautiful? No! In most cases the heating enhances the gemstone to make it more beautiful; the price premium is the result of the rarity of being unheated!

Heating

Heating is the most common treatment available. It can cause the color of a stone to lighten, darken, or change completely. It can bring about an improvement in clarity and brightness. Heating is detectable only by trained observers in a laboratory setting and is usually irreversible under normal conditions. Unheated rubies and sapphires will contain microscopic rutile needles or tiny gas bubbles in pockets of liquid which are evidence that laboratories can use to guarantee that these stones have not been heated. If these gems are the finest color they will command premium prices due to their extreme rarity.

Within the last couple of decades, it was discovered, quite accidentally, that if sapphires were heated along with a flux containing beryllium, the color of the sapphire could be dramatically changed. See diffusion below.

The following gems are routinely heat treated:

Tanzanite



Figure 13.1.1

Citrine



Figure 13.1.2

pink topaz
aquamarine
Paraiba tourmaline
apatite
ruby
sapphire
zircon (both blue and colorless)

Oiling

Oiling of emerald is universal, but not every emerald is oiled, (fine untouched specimens will command astronomical prices). When the rough emerald is mined it is thrown into a barrel of oil; when it is cut, oil is used as a lubricant on the cutter's lap. The colorless oil seeps into the fissures on the surface of the emeralds. When the fractures contain the oil they are less eye visible. To complete this process oil is pressurized into the fissures of the polished stone. This is something that must be accepted; it's the way it is! The only way you will find an emerald that isn't oiled is if there are no fractures at the surface of the emerald, so no oil can get inside the stone. If color is equal, obviously you will pay more for an emerald if it has no fissures that reach the surface; they simply will have fewer inclusions. If an emerald that originally had fissures that reached the surface,is put into an ultrasonic or is steamed clean, then the oil may be leached out and fractures. This will make the surfacing inclusions appear whiter and more obvious. In this case, the stone can be re-oiled.

Recently, other colored stones such as rubies, alexandrite, other varieties of chrysoberyl, and demantoid garnets have been treated with oils and resins to make surfacing inclusions less visible. Occasionally colored oils are used on emeralds and rubies. The idea is to add color while concealing fractures. You want to avoid buying these because you can't judge the true color or know how bad the fractures are. This is done to deceive the buyer. Fortunately, this is not common and it is unlikely you will encounter this if you buy from a reputable source in the United States. Synthetic resins can be used to fill in fractures in emeralds and other stones with fractures that reach the surface of the gem. Hardeners are often applied to make the process more permanent. The use of these resins, with hardeners (Like Opticon) are not acceptable treatments.

Irradiation

Irradiation means pounding material with subatomic particles or radiation. Sometimes irradiation is followed by heating to

produce a better or new color for the gem. Blue topaz is the most common example. Although blue topaz occurs in nature, it is quite rare and pale in color. In the United States irradiated gems are regulated by the Nuclear Regulatory Agency to in an attempt to insure there is no harmful residual radiation. You do not have this protection if you buy it out of this country. Today irradiation of blue topaz has created shades not found in natural blue topaz; prices are very reasonable for irradiated blue topaz since there is a great deal of competition in the wholesale end of this market. If you could find an untreated blue topaz, it would sell for a price comparable to untreated Imperial Topaz. Tourmaline can be irradiated to darken pink stones into red ones; these are indistinguishable from natural red ones. Off colored diamonds can be irradiated and heated and turned into intense greens, yellows, blues, browns & pinks. These stones are fairly common. Irradiated diamonds will sell for much less per carat than the naturally colored ones of comparable color, clarity grade, and size Cultured pearls can be irradiated to produce gray or blue colors; but dyeing in these colors is more common. Irradiated pearls will sell for about the same price as the dyed pearls, this should be well below the prices asked for pearls with very fine colors. Varieties of quartz and spodumene are irradiated and subsequently annealed with heat to produce dramatic and desirable colors.

Dyeing

Without dyeing there would be no black onyx: this is not a natural color of chalcedony! Chalcedony or more commonly known as agate, is often dyed blue, green, or orange and carved into bowls, statues, or cut into beads. This is fine, as there are some lovely pieces around using this stuff, especially carved animals and the like and no one minds that it's not "natural". Japanese cultured pearls, which are grown in an Akoya oyster that produces pearls up to about l0 millimeters, grow into a limited selection of colors with various overtones of colors. If they are dark gray, bluish, violet, nearly black, or intense bronze, assume they are dyed. To meet current demand for pearls with rose overtones, some cultured pearls have been given a pink tint; this can be detected by looking for concentrations of dye around drill holes or around blemishes. On the other hand, South Sea cultured pearls which are generally larger than the Japanese cultured pearls, may grow into a variety of exotic colors naturally because they are grown in a different variety of oyster. Tahitian black pearls are a good example of naturally colored black pearls. Cultured pearls with a natural exotic color will command a much higher price than a dyed one. Dyeing of chalcedony and of pearls is prevalent, permanent, and acceptable. These colors do not occur in nature; no deception is involved. Dyeing of other materials, jade, lapis lazuli, turquoise, coral, rubies, emeralds and sapphire may be less acceptable. Generally, dyeing of these materials is done to disguise poor quality goods. Dyed lapis lazuli can be easily tested by rubbing it with a piece of cotton soaked with acetone (fingernail polish remover). If it is dyed, blue color will eventually rub off on the cotton. Dyed lapis should be much less expensive than fine natural lapis. In the case of lapis lazuli or turquoise, the natural material is not that expensive, so why bother with inferior material unless it is irresistibly cheap or you just love the color? Dyed lapis lazuli may bleed blue onto the wearer or his or her clothing (not a fun thing to remove, trust me). Dyed jade may be tricky to detect, so be careful if the price seems "too good". An inexpensive tool (around $30) called a Chelsea Filter and supplement emerald filters can somewhat useful detecting dyed jade but the sophistication of the bleaching and polymer impregnation of jadeite can be extremely hard to detect without the aid of spectrographic analysis. Coral beads may also be dyed. Suspect coral that has a very intense color, coupled with an inexpensive selling price. I recently encountered strands of sapphire beads which were quench cracked and died. The treatment was easily visible with microscopic observation, but it did not bleed at all when soaked in acetone. Click Here for Additional Information on Jade Treatments Impregnation and stabilization Impregnation and stabilization are common for turquoise. Impregnation is the infusion of wax or paraffin into a porous material. Stabilization is the introduction of a bonding agent, usually plastic, into a porous material. Of the two processes, stabilization is the most permanent. Impregnated pieces must be kept away from heat or the wax could melt & leak... not a pretty sight. Some gems are waxed on the surface to enhance luster but this is not very usual. The upside for stabilized turquoise, is that it will not absorb oils and discolor as untreated turquoise may. Opal can be stabilized with plastic to hide crazing, but this is not common at all and would only be done to deceive the buyer.

Bleaching

Bleaching is a process for organic gem materials such as ivory, coral, and for pearls and cultured pearls. It lightens the color and is permanent and undetectable. No price difference exists as a result. Coating is a process (used and described for over 200 years! where a lacquer or film of some type is applied to improve a gem's appearance. Today, coatings are increasingly utilized to alter and improve the color of gems. Mystic topaz is an example of a coated gem that was conceived by Azotic Coating Technologies. The company is now coating topaz in all colors, including pinks and rich "imperial" tones. Recent reports have indicated that tanzanite is showing up in the labs with coatings on the pavilions to improve the appearance of saturation. Coatings are occasionally identified on diamonds to improve the apparent color of an off-colored stone and deceive a buyer. Opals may have a black coating on the back to intensify the play of color or to give the appearance of a black opal; this can take the form of a simple coat of black lacquer or what is called a "doublet." A doublet is a thin layer of opal cemented to a black onyx base.

Diffusion

Diffusion was originally used on sapphires. Chemicals, like beryllium, were infused at high temperatures, and actually penetrated the gems. Early diffusion only produced color on the surface of the gem's surface and was referred to as "Surface Diffusion". Surface diffusion was easily detectable with immersion, and often with simple magnification. Great advancements have been made in diffusion treatment in the last decade and it was discovered that if corundum is heated to very high temperatures for a long duration, the diffusion would penetrate the entire stone! It can improve color, change color, or create asterism (stars). Filling is used on gems with surface fractures or cavities. Glass, plastic or other materials are used to fill these holes. This is sometimes done to rubies. With close examination with magnification you may be able to spot differences in surface luster, or see a spectral effect in fractures when viewed with dark-field illumination. The AIGS, The Asian Institute of Gemological Sciences, has done extensive research on filled rubies.

Infilling Diamonds

Diamonds with inclusions are sometimes filled with glass to make them appear clearer. Oved and Yehuda Diamonds have undergone this treatment. Filler can be damaged by heat, ultrasonic cleaning, and by re-tipping. The filling does not repair the inclusion, it just makes it less visible. If you look at a filled diamond closely, rotate it under light, you should be able to notice a bluish flash. Both Yehuda and Oved will usually refill your diamond for free if it is ever damaged. Check for guarantees before buying such a diamond.

Lasering

Lasering is sometimes used on diamonds. The process drills very tiny holes into a diamond to provide access to an inclusion which detracts from the beauty of the stone. The inclusion can then be, vaporized or bleached to make it less obvious if it is not burned out by the lasering. Under magnification laser holes are visible when viewed at the correct angle. A lasered diamond would be classified in the slightly imperfect or imperfect category regardless of the improvement in apparent clarity and should be priced accordingly.

Gems that are Not Enhanced

There are some gemstones that are not known to be enhanced. These include: Garnets,(with the exception of demantoid), Peridot, Iolite, Spinel, varieties of Chrysoberyl, Tourmaline (with the exception of the Paraiba variety), Malachite, Hematite, and Feldspar with the probable exception of varieties of andesine and labradorite. Keep in mind that new technology in gemstone treatment is always changing and improving and many are seriously difficult, if not impossible, to detect.

Disclosure

With some gemstones enhanced by specifically defined treatments according to the guidelines of the CIBJO, it is a requirement of the Trade in the US to make such disclosures and in any case a vendor should always disclose any known treatments or enhancements (remember, they may not always know themselves, with imported Gems) and record it on your bill of sale. Most vendors are honest and forthcoming, but it is your responsibility to ask.

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13.2: Heat Treatment

Heating of Precious Stones

Following is a discussion of one of the oldest methods for gemstones enhancement.

By Alberto Scarani and Paolo Minieri

In previous articles, we have discussed how adding Beryllium with high-temperature treatments generates a change and improvement of color in corundum. Similarly, we have discussed several aspects of surface diffusion treatment, a modified system, by addition of foreign elements which become chromophores used for altering and embellishing gemstones: **the heat treatment**.

Before we move forward it will be useful to focus upon an essential aspect: the simple heating of a gemstone can greatly improve its appearance due to chemical changes in elements already present within the stone, or sometimes a combination of elements, when heated, can aid in the "healing" of fractures. The "healing of fractures is very important to distinguish from other heat enhancements methods, as it is more penalized when noted in Gemstone Identification Reports issued by major labs because foreign elements are often added. Truth be told, as we shall see ahead, even with simple heat treatments there are chemical exchanges between the gem and the surrounding atmosphere, but most labs consider this of minor significance.

It's practically impossible to establish a precise dating of the first gemstones heating experiments. Red agates and carnelians revealing evidence of heat treatment were produced in India in 2000 B.C.; many examples were also recovered from Egyptian tombs, including treasures found with Tutankhamen (Circa 1300 B.C.). In more than 4000 years, the procedure hasn't substantially changed! This will be apparent when you have a look at some elementary ovens that are still operational nowadays in the Chanthaburi area, Thailand and Cambodia. These ovens still produce at full speed heated gems of nice quality.

In the 19th century, the improvements in experimental sciences resulted in continuous upgrading of technical resources, allowing the development of ovens able to reach and easily maintain temperatures of 1500 °C or more. Nevertheless, we must say, that until the first studies were performed by Dr. G.O. Wild in 1932, the effectiveness of heating gemstones couldn't be reliably estimated even by the most expert "burners".

But How is common heat treatment performed? Although there are many variations of the procedure and a number of gems are involved, we can summarize by saying that there are two main elements involved: the temperature and the environment (atmosphere composition and pressure) in which it took place. The mechanism which allows the modifications is unleashed by raising the temperature. In the majority of cases, this allows chemical exchanges at atomic levels between the gemstone and its surrounding atmosphere.

There are many different effects which can occur when a stone is heated: from darkening to a color change/improvement, from a structural variation to a crack. It's clear that the main purpose of a treatment should be to improve the appearance of the gemstone. Therefore, the most interesting aspects will involve color and clarity modifications.
Color modifications can occur:

- in diamonds as the result of with irradiation, annealing
- In varieties of sapphire (adding or reducing color in yellow, green or blue hues)
- Ruby (modifying from browny or purple to red, from red to orange, and removing undesired color components)
- Aquamarine (modifying from green to blue)
- In other beryls (from yellow to colorless, from orange to pink)
- In endless quartz varieties (from amethyst to smokey quartz, cryptocrystalline quartz like carnelians, tiger eyes etc)
- Spodumene and Kunzite (from purple to blue, from green to pink or violet)
- Topaz and tourmalines (almost all of them abide the treatment)
- Zircon (from browny to reddish or blue, from green to blue or yellow)
- Tanzanite (a variety of zoisite) is an emblematic case: it originates in nature, an undesirable brownish-yellow color, only after the heat treatment those stones will get the worldwide-known beautiful purplish-blue color.

The most impressive clarity modification due to heat treatment occurs in sapphire and ruby corundum varieties. The technique

required for color modification/improvement that is needed is very similar to what is needed to achieve clarity modifications. It involves proper and controlled composition of the atmosphere. A reducing or oxidizing environment (higher or lower oxygen percentage) will allow, as an example, the exsolution of the rutile needles band of silk with consequent improvement of the transparency in milky, whitish or cloudy stones. The procedure could enhance, reduce or eliminate the asterism phenomena visibility. Exposing gemstones to high temperature often causes distinct modifications. Inclusions (several are often present) could suffer for distinctive alterations that, sometimes (rarely) could lead to irreparable damages. The different dilatation coefficient between the stone and included crystals often produce discoidal fractures surrounding them called tension halos which are very common to find in heated stones.

Another example of diagnostic evidence is the morphological modification of the included crystal shape; well defined, with straight surfaces and distinct edges in unheated stones, they will appear blemished, more rounded and free from clear edges in treated stones, in a direct proportional grade to the reached temperature.

Not always reaching very high temperatures is necessary. Considering the treatment timing length a variable connected with temperature (they're inversely proportional) we will be allowed to lower the heating (500-700 °c) if we can protract the treatment length. In this way, we will be able to drastically reduce heating effects to inclusions. The low-temperature heating is really difficult to spot by visual observations only, even for trained and skilled gemologist, very often the use of advanced apparatus like FTIR Spectrophotometer et al. is required. Nowadays heat treatment is widely accepted (if disclosed, of course) and in some cases (tanzanite, tourmaline, zircon, quartz etc..) is considered such a consolidate routine that very often the disclosure is unmentioned (among professional) in business procedures. It's good to know that in those described stones, only rarely the treatment will be considered of discriminative importance from the price point of view, in many other situations (in sapphires and rubies, for example) the importance of this factor is absolutely unavoidable. Nowadays many mines providing for high-quality gemstones are sterile or in the way of depletion while demand for such gemstones remains very high. This has led to attempts to make profitable low-grade materials by using enhancement treatments. It's the typical case of the so-called "Geuda" Sri-lankan sapphires (the name comes from singalese word used to describe grey-bluish low grade material) flooded the market in the second mid of 70' and of Mong-hsu Burma rubies appeared in huge quantity on the market in early 90'. Geuda sapphires are commonly near-colorless and the clarity is heavily affected by the abundant presence of rutile in clouds or silk bands shapes, this is in common with Mong-hsu rubies which have almost always distinct blue zoning affecting the color. In both cases, heat treatment allowed a terrific improvement of color (enrichment in Geuda sapphires, photo 10-11 and removing of the blue component in Mong-hsu rubies, foto 12) and clarity by silk (rutile) exsolution. Truth to be said, in Mong-hsu rubies treatment the adding of a foreign component (flux) was needed to permit the healing of the numerous fractures typical of that rough.

We can state without a doubt that the majority of the gemstones on the market are submitted to heat treatment of variable intensity on a regular basis (even if of minimum impact as in some aquamarine cases et al), without appreciable depressive effects on the price side which could be nevertheless considered far greater when the intensive use of foreign elements and/or other manipulations are performed.

Generally speaking, the demand for unheated gemstones is continually rising (In the USA, Japan and in some more frost European markets) principally due to their rarity but even for their incomparable beauty.
But, what about heated stones prices comparing to unheated? Just to have a clue, for a 1 ct unheated Sri-Lankan sapphire there's an average premium of 20-25%, things will significantly change if we go over 2, 3 or more cts, the price will be doubled, treble and much more in some particular cases.
And what about the Italian market? We are far late, as usual, but the trend shows a distinct and raising appreciation for unheated gemstones and for sure treatment-free will be more and more requested.

Temperatures for Individual Gem Treatments:

Aquamarine: 450 degrees Celcius changes the valence state of the iron
Amethyst to Citrine:: 450 degrees Celcius
Reddish Brown Zircon to Blue: 1000 degrees C in a reducing (oxygen free) environment
Reddish Brown Zircon to Colorless 900 degrees C in air
Orange Beryl to Morganite: 400 degrees C
Yellow and Brownish yellow topaz to Pink: 550 degrees C
Topaz (all colors) to Colorless:1000 degrees C
Dark Green Namibian Tourmaline will brighten Significantly:370 degrees C
Brownish Green Zoisite to Tanzanite:370 degrees C
Sapphire containing titanium to develop or brighten color:1600 degrees C

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- "Gemmology", Peter Read

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14: SYNTHETIC GEMSTONES

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14.1: Synthetic Gemstones

A Brief History of Synthetic Gems

From the earliest records in human history, attempts have been made to imitate precious gems. The ancient Egyptians used convincing colored glass and porcelain to mimic their most sacred stones, lapis, turquoise, and coral. Mining, in ancient history, had profound limitations, not the least of which was the limited amount of travel most cultures accepted as a reality of their lives. Early imitations were attempts to recreate the beauty found in nature. It is really doubtful that fraud was a motivation. Until the end of the 19th Century, glass and porcelain remained the mediums for imitating precious gemstones.

Chemical elements were discovered at the end of the Middle Ages. Developments in analytical chemistry were widespread in the 18th century. In chemistry, breaking a substance down to its elemental composition is known as "analysis". The composition of a substance from its basic elements is known as "synthesis". Synthetic gems are composed of the same elements as their natural counterpart. In addition, they also possess the same crystallographic and physical characteristics.

Technological advancements exploded in the 19th Century and provided the techniques for actually synthesizing gemstones. Early chemists were attempting to manufacture a synthetic product with the hardness and toughness of gems which would have industrial applications. Early synthetic gems were seen as an excellent and inexpensive alternative for watchmakers, not jewelers! Verneuil, a French chemist was the first to synthesize ruby in the late 1800's, and his technique, the " Verneuil Process" was mastered in 1902.

IG Dye Trust, in Germany, developed a diffusion melt process (utilizing R. Nacken's method) and synthesized the first emeralds in 1935. This method was also used by Chatham (USA), Gilson (France) and Zerfass (Germany) to synthesize gems. Further research by these firms, developed the more sophisticated flux fusion method which is still utilized by most manufacturers today. This method requires the use of fluxes which commonly leave a variety of natural looking inclusions in the synthetic gems.

Synthetic Gems Include

Diamond
Ruby
Sapphire (all colors)
Emerald
Aquamarine
Red Beryl
Spinel
Quartz (all colors including Amethyst, Citrine, and Ametrine)
Alexandrite
Opal
Fire Opal
Forsterite (used as Tanzanite imitation)
Peridot (not commercially available)

Artificial Products

Artificial Products are defined as crystalline gems produced by an artificial process which have NO natural counterparts. Their primary function is to imitate other gems, but their physical and chemical properties are not related to the stones they imitate.

Artificial Products Include

Moissanite
Strontium Titanate
Yttrium Aluminum Garnet (YAG)
Gadolinium Gallium Garnet (GGG)

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14.2: Sublimation

The sublimation method to create synthetic materials is a method where a solid is heated at appropriate temperatures and pressure, usually in a near vacuum, so that it goes from the solid state directly into the gaseous state, skipping the liquid state. The gas then condenses as a solid, again skipping the liquid state. A material famous for this is CO_2 (dry ice); at room temperatures and normal atmospheric pressure, this solid block of ice will immediately sublime into a gas.
Synthetic moissanite is the main synthetic gemstone produced by this process.

There are several different setups to accomplish this, most of them use a seed plate and a powder source. Another way is by the use of gasses and a seed plate.

Powder method

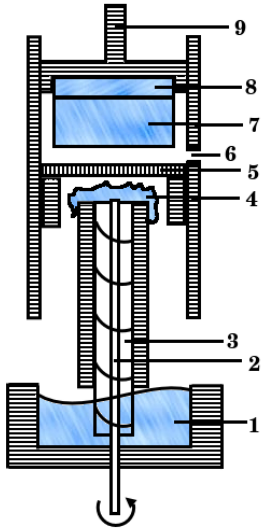


Figure 14.2.1

Below follows a summary of the sublimation method used to create synthetic moissanite (silicon carbide), for a detailed explanation we refer to the patent description.

Above is a cross-section of the cylindrical graphite crucible that is held inside a larger, evacuated, furnace.

A powder of silicon carbide (**1**) is transported by a screw (**3**), that works like an Archimedes Screw, just underneath a porous graphite plate (**5**). That screw is rotated by a rod (**2**).
When the powder reaches the stage just below the porous plate, it is heated at around 2,300° C and the powder goes into the gaseous state (**4**). This temperature is the sublimation temperature.

The surface of the seed crystal (**8**), or the growing crystal (**7**), is kept at a temperature just below the sublimation temperature (2,200° C) and the silicon carbide gas condenses at the surface of the seed crystal or the growing crystal.

An opening (**6**) in the annular, graphite crucible holds an optical pyrometer that monitors the temperature of the seed's or growing crystal's surface. The seed crystal (**8**) is held by a mount (**9**) that in some setups can be lowered/raised/rotated depending on what the pyrometer indicates.

Silicon carbide is a good semiconductor with a large bandgap (+3 eV) and one could expect the produced crystals to be colorless. However n-type dopants (nitrogen) in the furnace create color centers. This is solved by adding an equal amount of a p-type dopant (aluminum) to the powder source, in effect canceling each others color centers.

Gasses method

In this adaption, the powder is substituted by two gasses, silane (SiH_4) and ethylene (C_2H_4). When these two gasses combine together at a temperature of about 2,400° C, they will react and form a silicon carbide gas. This gas will then condense the same way as the powder source.

References

- 1995 patent that describes the production of large silicon carbide crystals through sublimation
- The 1998 Cree Research, Inc. patent

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14.3: Skull Crucible

The "skull-crucible" or "skull-melting" method is mainly used to create synthetic cubic zirconia (at least when it comes to synthesizing gemstones).
The "skull" part refers to the thin crust (or skull) of white zirconium dioxide that is formed around the crystallized core.

Although zirconia (ZrO_2) occurs naturally, it is mainly monoclinic of nature and is known as baddeleyite. The cubic form, known as "arkelite" occurs sometimes in zircon.

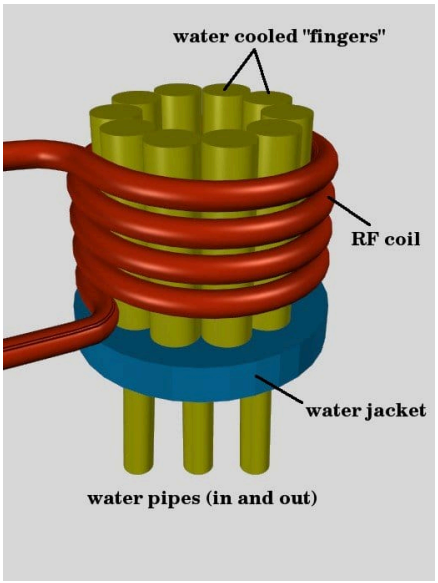


Figure 14.3.1***:*** *Skull-crucible furnace*

The synthesizing of cubic zirconia posed two main problems throughout the 20th century. The melting point of zirconium dioxide was so high (2750°C) that none of the usual crucibles (platinum etc) could withstand that heat. The other problem was that ZrO_2 tends to crystallize as monoclinic crystals instead of in the cubic system.
The first barrier was taken by letting the zirconium dioxide powder form its own crucible (a skull) and the second by adding stabilizers as yttria (Y_2O_3) or calcium oxide (CaO). The mole percentage of the stabilizers varies from 10 to 30% (usually 15% for yttria and 10% for calcium oxide).

In order to create the high temperatures that are needed to melt zirconium oxide, radio-frequency (RF) waves are used. These have a frequency of about 4MHz with a voltage between 50 and 100kW (enough to power your favorite radio station). This RF induction only works on good electrical and thermal conductors, zirconium dioxide not being one of them. This is solved by placing a rod of zirconium metal in the center of the crucible (which will react and turn into cubic zirconia itself).

The zirconium metal and the zirconium dioxide source powder are placed inside the crucible (between the fingers) and the system is turned on. Water pipes provide a flow of cold water to the copper "fingers" that line the crucible, keeping the outer perimeters of the source powder cool (preventing it from melting).
The radio waves that pass through the copper RF coil heat up the zirconium metal which in turn heats up the surrounding powder. As this powder melts it becomes receptacle to the RF induction and in turn, melts its surrounding powder. This goes on until the powder that is close to the cooled fingers prevents it from melting.
The workings are similar to how a kitchen microwave oven works (but not the same).

After the induction, the melt is slowly lowered from the coil and the energy of the coil is adjusted in order to keep the melt between the coil at about 1400°C. During this slow lowering (ranging from 2 to 30mm/hour, depending on the composition of the melt) columnar crystals are formed and relieved from stress. With a furnace height of 200mm, this takes an average of 12 hours. When the total, now crystallized, mass reaches a temperature of 98°C, the melt with the surrounding "skull" is taken out of the furnace and left to cool in the open air, after which it is parted with a slight tap of a hammer.

A typical run needs 1 kilogram of powder and will yield 500 grams of gem material cubic zirconia.

As mentioned earlier, in order to prevent the molten mass to crystallize in the monoclinic system, a stabilizer is added to the melt. This can be either yttria or calcium oxide. Each of these two will give slight variations in optical and physical properties.

In addition to the stabilizers, other elements can be added as dopants to create colored crystals. Some of them are: cesium, chromium, iron, cobalt, neodymium, praseodymium, vanadium, copper and manganese.

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14.4: Flame Fusion

The flame fusion method (also known as the "Verneuil process") to grow synthetic gemstones was created in 1893 by Auguste Victor Louis Verneuil (1856-1913) as a means to grow synthetic corundum. In 1904 Verneuil shared his knowledge with the world in a publication in the French journal "Extrait des Annales de Chimie et de Physique" and his technique is still used today, either with or without slight adjustments, to grow a variety of synthetic gems as corundum. spinel, rutile and strontium titanite.
Due to the high polish, this synthetic corundum can take (and its relative high hardness) the produced crystals were, and still are, in high demand by the watchmaking industry. Either as bearings or as watch glasses.

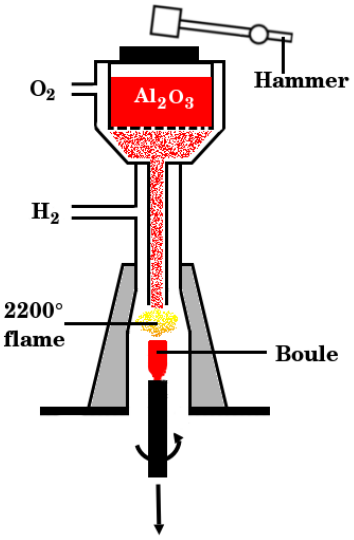


Figure 14.4.1***:*** *Simplified flame fusion (Verneuil process) diagram to grow synthetic corundum*

In order to grow synthetic corundum (or another mineral that is suitable), a feed of source powder is held in a container with a sieve-like floor. On tapping with a hammer, the container releases a certain amount of the powder that is fed into a chamber and mixed with compressed oxygen. One can compare this with tapping against a kitchen sieve to dose flour or powdered sugar.
The powder with the extra oxygen falls down into an ignited oxyhydrogen flame (at around 2200° C) and the feed powder starts to sinter onto a ceramic rod (named a "candle"). At first, the powder is allowed to create a "starter" mass on which the rest of the sintered powder will grow.
When the "starter" boule has formed, the rate at which the hammer hits the powder container is decreased and the oxygen/hydrogen mixture is adjusted to the most favorable circumstances. The ceramic candle is lowered from the flame at a constant rate to keep the top of the growing mass in the hottest part of the flame to let the boule grow.
Typical produced boules grow up to about 100mm in length and with a 20mm diameter (although they are not round in cross-section). The "candle" pedestal is lowered at a rate of 10mm/hour, thus a finished boule of 100mm in length would take 10 hours to create.

After growth, the boule is broken from the candle and parted lengthwise to relieve it from stress.

The name "boule" comes from the French word for swelling and refers to the ball-like appearance of the first results. A correlation with the French game "jeu de boules" (game of balls) is easily made. Nowadays the term "boule" is applied to the whole finished, cylindrical, product.

Although the technique sounds easy, it, in fact, requires careful control of all the steps involved, including temperatures and position of the boule.

It is estimated that 90% of the artificial production of synthetic corundum is done through the flame fusion method [Hughes, 1997].

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14.5: Synthetic Forsterite

Although forsterite does occur in nature, it is not suitable to be cut into gemstones. As from 1999 large size synthetic forsterites have been created in Russia by the Czochralski pulling technique.
Due to physical and optical properties that lie close to tanzanite, this synthetic is used mainly to imitate tanzanite.

Chemical composition

Mg_2SiO_4, magnesium sillicate.
Forsterite is one of the end members of the isomorphous group to which peridot (olivine) belongs (fayalite-forsterite series).

Diagnostics

One of the easiest and most important techniques in separation synthetic forsterite from tanzanite is by observing the "doubling of back facet edges" (double refraction) due to the high birefringence of synthetic forsterite. This feature is easily visible on examination in various directions using a loupe.
Tanzanite with a birefringence of 0.008 to 0.013 will not show such a strong doubling effect.

Hanneman Tanzanite Filter

Another quick method to separate synthetic forsterite from tanzanite is with the aid of a Hanneman Tanzanite Filter. This is a filter that combines the Hanneman Aquamarine filter with a London dichroscope.
Synthetic forsterite will show up green through the filter part, while tanzanite will show a pinkish-orange color.

Refractometer

The refractive indices of synthetic forsterite are lower than that of tanzanite.
1.634-1.670 (tanzanite: 1.685-1.707).
Forsterite's birefringence is much higher than that of tanzanite: 0.033 - 0.038 for forsterite, 0.008 - 0.013 for tanzanite.

The optic character of pure forsterite is biaxial with a positive optic sign (the same as tanzanite). One will sometimes read forsterite to be biaxial -, however, if olivine consists of 100 to 85% forsterite (0 to 15% fayalite) it is biaxial +.
In practice, synthetic forsterite will be biaxial with a positive optic sign.

Fluorescence

Synthetic forsterite will show a weak greenish-yellow under SW-UV and a chalky orangy-yellow under LW-UV. Tanzanite is inert to both.

Update

Natural colorless forsterite has been found in Mogok, Burma (Myanmar) as of early 2008. Originally thought to be a member of the humite group, testing at the GIT and the GIA Laboratory in Bangkok confirmed that the stones were forsterite.

References

- Insider Gemologist: What Are the Identifying Characteristics of Tanzanite, and How Is It Distinguished from Imitations? (2004) - GIA

- Gems Their Sources, Descriptions and Identification *4th Edition (1990) - Robert Webster (6th ed.)*
- Introduction to Optical Mineralogy *3rd edition (2003), Prof. W.D. Nesse*

- Manufactorers data of synthetic forsterite - Provided by Morion Company

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14.6: Synthetic Moissanite

Moissanite is a naturally occurring mineral that is named after its discoverer, 1906 Nobel Prize (chemistry) winner Henri Moissan (1852-1907). As a natural source, this mineral is not suitable to be cut into gemstones as it occurs in too small grains and is very rare.
Moissanite (silicon carbide) was synthesized (1893) before it was discovered (1905) in nature.

Synthesizing moissanite has never been a real problem, however, at first it was only synthesized for industrial purposes. This material, with a hardness of 9.25 on Moh's scale, is known by many bench jewelers, lapidarists and dentists as "carborundum" and is widely used as a sharpening tool for gravers and scrapers. As many who use carborundum can testify, this material is not very attractive as a gemstone.
Around 1987 Cree Research found a method to produce gemstone quality synthetic moissanite, but it was not until 1993 that a near-colorless crystal was obtained. The technique was patented in 1998 and the synthetics are created with the sublimation method. Today this gemstone synthetic is marketed as *Charles & Colvard created Moissanite*™.

Although a nice synthetic on its own, this material is used mainly as a diamond simulant. Since the arrival of synthetic cubic zirconia in 1976, this is the most convincing diamond simulant, although a trained eye can easily separate synthetic moissanite from diamond.

Diagnostics

Synthetic moissanite can be easily separated from diamond by the doubling of facets, due to its high birefringence. Synthetic moissanite is usually cut with the table cut perpendicular to the optic axis, so care should be taken to observe the stone from an angle to the table.
Other clues are parallel needles (along the optic axis) and pinpoint inclusions in synthetic moissanite.

Refractometer

Synthetic moissanite has a refractive index higher than diamond and the standard gemological refractometer will not be of any help.
The "dot test" will not help much either, but it will separate synthetic moissanite from zircon.

Dispersion

The dispersive power of synthetic moissanite is about 2.5 times higher than that of diamond and the excessive "fire" should raise a red flag immediately.

Specific gravity

The specific gravity of moissanite is lower than that of diamond and it will float in methylene iodide (SG = 3.33) while diamond will sink in it.

Magnification

The doubling of facets in faceted stones will easily separate synthetic moissanite from diamond.
Typical inclusions include:

- Parallel needles along the optic axis
- Pinpoint inclusions, often in clusters

Polariscope

Synthetic moissanite is uniaxial so it will show an anisotropic reaction under crossed polars.
The interference pattern is uniaxial with a positive optic sign (like zircon).

Spectrum

There is a usual absorption in the violet from 400 to 425nm and this could be confused with the 415nm line in cape series diamond.

Electronic testers

Most electronic diamond testers like from Presidium are created to test the thermal conductivity of the gem. Synthetic moissanite is a good thermal conductor like diamond and this test will fail with the usual testers.
There is a special moissanite tester on the market that does distinguish between diamond and synthetic moissanite, but there are far less expensive techniques available to make the distinction.

References

- Synthetic moissanite: A new man-made jewel - Kurt Nassau, Current Science Vol 79 No 11, 10th Dec 2000 (Indian Academy of Science).
- Scottish Gem Lab News June 1998 by Alan Hodgkinson

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14.7: Synthetic Cubic Zirconia

Synthetic cubic zirconia (CZ) entered the market as a gemstone around 1976 and is still presently the most widely used diamond simulant. Although cubic zirconia is found in nature (as minute crystals inside zircon), the more stable variant of zirconia crystallizes in the monoclinic system (baddeleyite).
The main means of syntheses is through the "skull crucible" aka "skull melting" method.

Chemical composition

Zirconia has the chemical formula ZrO_2, this material, however, will not crystallize in the cubic system through syntheses. A stabilizer of yttria or calcium oxide needs to be added to the source powder in order to let it crystallize as isotropic crystals.

Diagnostics

As synthetic cubic zirconia (CZ) is mainly used to imitate diamond one can expect the main separation techniques to concentrate on distinguishing between the two.

Color

Synthetic cubic zirconia is produced in a large array of colors, from colorless to black. Many coloring agents, including rare earth elements, are added to the source powder.

- Cesium: yellow, orange, red
- Copper, iron, nickel, praseodymium, titanium: yellow, amber, brown
- Erbium, europium, holmium: pink
- Chromium, thulium, vanadium: green
- Cobalt, manganese, neodymium: lilac, violet, purple, blue

Diaphaneity

Transparent to opaque.

Refractometer

Cubic zirconia has an RI that cannot be measured with a standard gemological refractometer. There are however other tools available, as the Hanneman-Hodgkinson refractometer or the Brewster angle meter, to determine the RI of CZ.

The optical properties of CZ vary slightly depending on which, and how much, stabilizer is used (yttria or calcium oxide).

- Yttria stabilized cubic zirconia: RI = 2.171, dispersion = 0.059
- Calcium oxide stabilized cubic zirconia: RI = 2.177, dispersion = 0.065.

The values of CZ are above the limits of the standard gemological refractometer. There are however a few other tests one can perform.

- The "dot test" will show a ring around the culet if the stone is cut to diamond brilliant proportions.
- The "tilt test" will show leakage.

Polariscope

CZ may show anomalous extinction.

Specific gravity

The SG of CZ is about twice that of diamond (3.52) and loose stones will have a higher "heft".
As with the refraction indices, the SG of CZ varies between stabilizers used.

- Yttria-stabilized cubic zirconia: SG = 5.95
- Calcium oxide stabilized cubic zirconia: SG = 5.65

Hardness

- Yttria-stabilized cubic zirconia: hardness = 8.25 (Mohs' scale)
- Calcium oxide stabilized cubic zirconia: hardness = 8.5 (Mohs' scale)

Luminescence

Colorless CZ stabilized by calcium oxide will show a yellow fluorescence.

Phenomena

Color change synthetic cubic zirconia is not uncommon and may show dramatic changes in natural/incandescent lightning.
Opalline (milky) CZ's are also produced. These are mainly opaque.

References

- The 1972 patent to create "Fianit" (synth. cubic zirconia) from Lebedev
- Gems Their Sources, Descriptions and Identification *4th Edition (1990) - Robert Webster (6th ed.)*

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14.8: Imitation Gemstones

Imitation Gemstones

Imitation gemstones merely imitate the color or look of a natural stone. They can be made out of anything. A cubic zirconia is an imitation diamond, for example. A blue piece of glass could be an imitation sapphire. A variety of blue synthetic forsterite is an excellent imitation for tanzanite, while chemically, it's composition is much closer to the yellowish green peridot. Another classic example is the "alexandrite" set in many jewelry pieces is actually a variety of vanadium colored synthetic sapphire.

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15: VISUAL OPTICS

15.1: Visual Optics
15.2: The Hodgkinson Method

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15.1: Visual Optics

Visual Optics is a term introduced to gemology by Alan Hodgkinson. It describes the technique of extracting valuable information from a gemstone just by looking through it towards a point light. Alan was sitting in his car one night, waiting in the presence of a box of reference stones, when he started looking through them towards a street light. The phenomena he observed proved to be in direct relation with the gemstone's RI and dispersion. The subject was studied further and his findings were shared through his book 'Visual Optics' which was first published in 1979.



Figure 15.1.1***:*** *Woodcut from Dieulafait, 1874, ("Diamonds and precious stones") of a man doing "Visual Optics".*

The technique with which a gemologist can estimate a gemstone's RI by eye & light alone is aptly called The Hodgkinson Method. It works by pattern recognition and, with practice, may lead to positive ID's of gemstones by anybody that is willing to take the time to master the technique.

The Hodkinson Method hasn't been adopted into the curricula of the big gemology schools. One may wonder why; the easiness and usefulness of the method are evident.

Gemologists from the past have used this method but it appears that it was solely used to distinguish double refractive stones from single refractive ones. One reference is found in a book written by Dieulafait which was published in 1874 titled 'Diamonds and precious stones. The text describes the method in order to determine the refractive nature of a stone by checking for object doubling when looking through it towards a flame or object.

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15.2: The Hodgkinson Method

This method is an interesting method and a unique approach to the determination of indices of refraction. It has the huge advantage of requiring no special equipment at all, beyond a human eye. It does require a darkened room, a small bare filament light source, and much practice. By merely looking through a faceted gemstone at a tiny light source, one can learn to estimate the index of refraction by displacement of the image he sees, birefringence by image separation and dispersion by spectral color fringes on the image. This may well prove a useful skill for one who travels much or operates without standard gemological equipment.

All you need are your eyes and some clean hands.

Pick up a stone in question and hold it up very close to your eye so that you can look into the table. You must hold it very close without touching – almost like inserting a contact lens, but again not touching. Look literally through the stone at a distant source of light such as a lamp or light bulb. You will see a number of reflections of the distant light source as they bounce around within the stone.

Roll the stone around its axis and tilt it slightly while watching the reflections. Due to the refractive properties of gemstones, each reflection will to some extent appear as a small rainbow. This is a single one of those rainbows as it appears looking through a spinel at the filament of a clear light bulb about 6 feet away:

Depending on the gem material in question, that rainbow will have varying properties. If the gem is doubly refractive you are likely to see doubled or ghosted (rainbow) images. Because the gem may be cut in any orientation with respect to the crystal structure (which is responsible for these phenomena) you may have to examine the stone from a variety of angles to be sure whether it is doubly refractive or not.

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16: GEMSTONES

16.01: Alphabetical List by Gemstone Name

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16.3.2: Sapphire

16.04: Beryl

16.4.1: Aquamarine

16.4.2: Bixbite

16.4.3: Emerald

16.4.4: Vanadium Beryl

16.4.5: Goshenite

16.4.6: Green Beryl

16.4.7: Heliodor

16.4.8: Maxixe

16.4.9: Morganite

16.4.10: Riesling

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16.4.12: Pezzottaite

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16.5.2: Ametrine

16.5.3: Citrine

16.5.4: Prasiolite

16.5.5: Rock Crystal

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16.5.7: Sunset Quartz

16.5.8: Smokey Quartz

16.06: Quartz - Polycrystalline

16.6.1: Chalcedony

16.6.1.1: Agate

16.6.1.2: Arkansas stone

16.6.1.3: Bloodstone

16.6.1.4: Carnelian

16.6.1.5: Chrysoprase

16.6.1.6: Jasper

16.6.1.7: Onyx

16.6.1.8: Sard
16.6.1.9: Sardonyx
16.6.1.10: Tigereye

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16.8.6: Uvarovite

16.09: Diopside
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16.9.2: Tashmarine™

16.10: Feldspar
16.10.01: Amazonite
16.10.02: Andesine
16.10.03: Labradorite
16.10.04: Moonstone
16.10.05: Spectrolite
16.10.06: Sunstone

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16.11.02: Kunzite

16.12: Chrysoberyl
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16.13: Spinel

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16.14.02: Achroite
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16.14.04: Indicolite
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16.21: Azurite
16.22: Barite
16.23: Benitoite
16.24: Bowenite
16.25: Calcite
16.26: Charoite
16.27: Clinohumite
16.28: Copal
16.29: Coral
16.30: Danburite
16.31: Datolite
16.32: Diaspore
16.33: Dioptase
16.34: Ekanite
16.35: Enstatite
16.36: Fluorite
16.37: Obsidian
16.38: Goldstone
16.39: Hauyne
16.40: Hematite
16.41: Iolite
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16.45: Kyanite
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16.47: Larimar
16.48: Malachite
16.49: Maw-sit-sit
16.50: Opal

16.50.01: Black Opal
16.50.02: Blue Peruvian Opal
16.50.03: Boulder Opal
16.50.04: Fire Opal
16.50.05: Pink Opal

16.51: Pearl
16.51.01: Sea of Cortez Pearl
16.51.02: Quahog

16.52: Pectolite
16.52.01: Larimar

16.53: Peridot
16.54: Phenakite
16.55: Pouretteite
16.56: Prehnite
16.57: Pyrite
16.58: Rhodochrosite
16.59: Sapphirine
16.60: Scapolite
16.61: Serendibite
16.62: Siderite
16.63: Sodalite
16.64: Hackmanite
16.65: Sphalerite
16.66: Sphene
16.67: Taaffeite
16.68: Topaz
16.69: Turquoise

16.70: Vesuvianite
16.70.01: Idocrase
16.70.02: Californite

16.71: Willemite
16.72: Zincite
16.73: Zircon

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16.01: Alphabetical List by Gemstone Name

A

Achroite
Agate
Akoya Pearl
Alexandrite
Almandine Garnet
Amazonite
Amber
Amethyst
Ametrine
Ammolite
Anatase
Andalusite
Andesine
Andradite Garnet
Apatite
Aquamarine
Arkansas stone
Axinite
Azurite

B

Barite
Beryl
Benitoite
Bi-color tourmaline
Bixbite
Bloodstone
Bowenite

C

Calcite
Californite
Carnelian
Chalcedony
Chalybite
Charoite
Chrome Diopside
Chrome sphene
Chrome Tourmaline
Chrysoberyl
Chrysocolla
Chrysoprase
Citrine
Clinohumite
Conch pearl
Copal
Coral

Cordierite
Corundum
Cubic zirconia (synthetic)
Cyprine

D

Danburite
Datolite
Demantoid Garnet
Diamond
Diaspore
Diopside
Dioptase
Dravite Tourmaline

E

Ekanite
Emerald
Emerald-Vanadium
Enstatite

F

Feldspar
Fluorite
Freshwater pearl
Forsterite (synthetic)

G

Garnet
Goldstone
Goshenite
Green Beryl
Greenovite
Grossular

H

Hackmanite
Hauyne
Heliodor
Hiddenite
Hydrogrossular Garnet

I

Idocrase
Inclusion quartz
Indicolite Tourmaline
Iolite

J

Jade
Jadeite
Jasper

K

Kornerupine
Kunzite
Kyanite

L

Labradorite
Lapiz Lazuli
Larimar
Liddicoatite Tourmaline

M

Malachite
Maw-sit-sit
Maxixe Beryl
Melo melo pearl
Moissanite (synthetic)
Moonstone
Morganite

N

Nephrite

O

Onyx
Opal

P

Paraiba type Tourmaline
Pearl
Pectolite
Peridot
Phenakite
Poudretteite
Praseolite (cordierite)
Prasiolite (green quartz)
Prasolite (chlorine group)
Pyrope Garnet

Q

Quahog
Quartz

R

Reisling Beryl
Rhodochrosite
Rock Crystal
Rose Quartz
Rubellite Tourmaline
Ruby

S

Sapphire
Sard
Sardonyx
Scapolite
Schorl Tourmaline
Sea of Cortez pearl
Siderite
Sodalite
South Sea Pearl
Smoky Quartz
Spectrolite
Spessartite Garnet
Sphalerite
Sphene
Spinel
Spodumene
Sunstone

T

Tanzanite
Tashmarine Diopside
Tigereye
Titanite
Thulite
Topaz
Tourmaline
Tri-color Tourmaline
True Blue Beryl
Tsavorite Garnet
Turquoise

U

Uvarovite

V

Vanadium Beryl
Verdite Tourmaline
Vesuvianite

W

Watermelon Tourmaline
Willemite

X

Y

Z

Zincite
Zircon
Zoisite
Zultanite

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16.02: Diamond

Diamond	
Chemical composition	C
Crystal system	Cubic
Habit	Octahedral, cubic
Cleavage	Perfect (octahedral)
Fracture	Conchoidal
Hardness	10
Optic nature	Isotropic
Refractive index	2.417
Birefringence	None
Dispersion	High, 0.044
Specific gravity	3.52
Lustre	Adamantine
Pleochroism	None

Figure 16.2.1***:*** *The Hope Diamond weighs 45.52 carats*

Diamond is a polymorph (many forms) of the element carbon. Graphite is another polymorph. These two minerals share the same chemistry -- pure carbon -- but have very different structures and properties. Diamond is hard, graphite is soft (the "lead" of a pencil). Diamond is an excellent electrical insulator, graphite is a good conductor of electricity. Diamond is the ultimate abrasive, graphite is a very good lubricant. Diamond is transparent, graphite is opaque. Diamond crystallizes in the isometric system and graphite crystallizes in the hexagonal system. Somewhat of a surprise is that, at surface temperatures and pressures, graphite is the stable form of carbon. In fact, all diamonds at or near the surface of Earth are currently undergoing a transformation into graphite. This reaction, fortunately, is extremely slow.

Diamonds have long been valued for their supreme hardness and incomparable brilliance. Chemically, a diamond is pure carbon just like the graphite used in pencils. Diamond's hardness is the result of extremely strong covalent bonding between the carbon atoms. Although most people think of diamonds as colorless, they actually occur in almost every color. Diamonds were viewed as talismanic by the ancient Hindus in India, which is where diamonds were first discovered. The most powerful stones were thought to be naturally occurring octahedrons of exceptional clarity which exhibited fire. These stones would bring the owner power, wealth, everlasting youth and good fortune. It was believed that flawed or inclusive stones could have quite the opposite effect. During the 1st century AD, prominent Romans wore uncut diamonds set in rings also as talismans. For hundreds of years, it was believed diamonds had gender. As late as 1566, Francois Ruet described two diamonds as having offspring. The first diamond engagement ring was given to Mary of Burgundy by Maximillian in 1477, thus establishing the tradition.

Diagnostics

Color

Diamonds are found in all colors, but diamonds most commonly occur in shades of yellow and brown. Colorless diamonds which are graded D-E-F are much rarer. The rarest colors are reds, blues, pinks, and greens of intense saturation.

Dot test

When a well proportioned brilliant is placed, table down, on a sheet of white paper with a black dot on it, the dot should not be visible through the pavilion of the stone. This is due to total internal reflection.
Diamond simulants with a lower index of refraction will show the dot on multiple pavilion facets, in a ring pattern.
Similarly, when a clear brilliant of good cut is placed over a colored piece of paper, the color will not shine through.

Brilliants that are not well proportioned, as fish-eyes, may also show the ring of dots, so one should assess the diamond's cut first.

An alternative way of performing this test on set stones with an open back, such as solitaires, is to enscribe the dot on the table and observe it from the pavilion. Be sure the dot can be easily cleaned after.

Spectrum

Figure 16.2.2***:*** *Spectrum of yellow diamond*

Figure 16.2.3***:*** *Spectrum of brown diamond*

Diamond Grading: The 4 C's

The 4 C's, when referring to diamond value, are color, clarity, cutting proportions and carat weight. All four components are equally important in determining the final value of a diamond. The criteria for diamond grading, most respected internationally, was developed by the Gemological Institute of America (the G.I.A.), during the 1950s. The following terminology and systems described are those of the G.I.A.

Color Grading

Diamondcolorscale.jpg

Figure 16.2.4

The color of a diamond refers to the relative amount of yellow, brown or gray body color that a stone possesses. The G.I.A. scale starts at "D" and goes through "Z", with "D" being void of any body color, and "Z" having a light yellow, brown or gray color.

Clarity Grading

Clarity grading of diamonds is defined by visual observation by a professional with the aid of a 10x loupe or the naked eye.

The most used system is the GIA system of clarity grading.

Table 16.2.1

Main grade	Subgrade		Short grade explanation
Loupe clean	**FL**	Flawless	Internally and externally flawless when examined with a loupe
	IF	Internally Flawless	Internally flawless

VVS	**VVS 1**	Very very slightly included (high end-close to IF)	Very, very small inclusions may be visible when examined with a loupe but the inclusions are not on the table
	VVS 2	Very very slightly included (low end-close to VS 1)	Very, very small inclusions may be visible when examined with a loupe The distinction between VVS 1 and VVS 2 is only made for stones above 0.5 ct
VS	**VS 1**	Very slightly included (high end-close to VVS 2)	Very small inclusions are present that are hard to see with the loupe but the inclusions are not on the table
	VS 2	Very slightly included (low end-close to SI 1)	Very small inclusions are present that are hard to see with the loupe
SI	**SI 1**	Slightly included (high end-close to VS 2)	Small inclusions are easily observed with the loupe but the inclusions are not on the table
	SI 2	Slightly included (low end-close to I 1)	Small inclusions are easily observed with the loupe
I	**I 1**	Imperfect 1	Inclusions are hard to observe with the naked eye, but easily with the loupe
	I 2	Imperfect 2	Inclusions are hard to observe with the naked eye but occur in multiple sites
	I 3	Imperfect 3	Inclusions are very easily observable with the naked eye and interfere with the brilliance of the stone

Cut: Proportion Analysis

Carat Weight

Carat is a unit of internationally recognized metric weight and does not refer to size. There are 5 carats in a gram. The weight of a diamond is measured in carats. A carat is divided into 100 parts, each called a point. Each point weighs 2 milligrams.

Durability

Diamonds are the hardest of all gemstones in their ability to scratch, but they can be broken along their four planes of inherent cleavage. Historically, it has been a very foolish practice to test for identification by using a diamond phonograph needle to scratch a suspected diamond. Only a diamond can scratch a diamond and semi-destructive testing of this sort is not necessary, given modern gemological instrumentation such as thermal inertia testing devices. Diamonds and many other hard gemstones easily scratch glass, so this is also a useless test of identification. Fashioned or cut diamonds are vulnerable to chipping at the polished or unpolished girdle edge as well as at the bottom of the pavilion which is known as the culet. The culet is the smallest possible facet and may or not be present. Diamond cutters usually strive for maximum weight retention from the rough and sometimes omit the culet. Small culets are considered acceptable by diamond graders and serve as the 58th facet in what is known as the standard "round brilliant cut."

Localities

Diamond deposits are found worldwide, the most notable deposits being on the continents of Africa and Australia, India, and most recently Canada.

Treatments

Definition
Diamond treatments refer to the processes done to alter the appearance of a diamond by enhancing one of the qualities of the stone, most commonly its clarity or color.

Laser Drilling

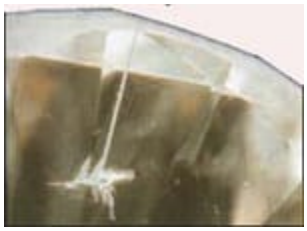


Figure 16.2.5***:*** *Laser Drill Hole*

This treatment involves pointing a high powered laser directly at a dark inclusion within a diamond and burning a tiny tunnel towards it. With luck, the inclusion will be altered enough by the heat of the laser to make it less noticeable. If that is not the case, a strong acid can be forced down the drill hole which will dissolve the inclusion and make it less obvious. This treatment is usually easily detected with 10x magnification. The drill hole breaks the surface of the diamond and leads in a straight line to the treated inclusion. Occasionally drill holes can be filled with glass (the same process as clarity enhancement) which makes them more difficult to detect with magnification. Laser drilling was first encountered in the 1960s.

In 2000, a new type of laser drilling was developed in Israel. It is called Kiduah Meyuhad (KM). The laser focuses on an inclusion within a diamond, and causes a series of internal fractures that make the inclusion appear to "bleach out". This laser treatment looks more natural and leaves no drill holes. It resembles feather like inclusions in the diamond, which do not break the surface. Detection of diamonds that have been treated with KM can be very difficult and requires the examiner to have experience in recognizing the characteristics of these microscopic fractures. Some KM treated diamonds have not been detected by major gem labs when grading.

Coating

Diamonds have been coated to disguise a low color grade, or to produce "fancy colors". The stability of the treatment varies, depending on the method used. Coated stones need special care, as aggressive ultrasonic cleaning, repairs, or re-cutting may destroy the integrity of the coating and totally change the appearance of the stone.
For more information, read this article from Gems & Gemology.

Clarity Enhancement

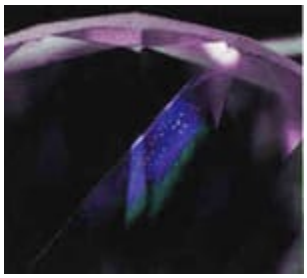


Figure 16.2.6***:*** *The "flash" in a clarity enhanced diamond*

Clarity enhancing a diamond involves replacing the air in a surface reaching crack or cleavage with a substance having a similar refractive index to the diamond. This changes the relief of the inclusion making it much more difficult to see. Clarity enhancement can have a dramatic effect on improving the look of a diamond.

To the trained eye, clarity enhanced diamonds are usually detected easily with magnification. The early examples of this technique produced broad flashes of color, bright red, violet, and orange, in the areas of treatment. The early glass filling was not very stable and was often damaged or destroyed with ultrasonic cleaning, repairs or normal wear.
The new generation of clarity enhancement does not produce the obvious flashes of color when viewed with magnification. Although, careful observation can reveal gas bubbles, flow patterns and partial crystallization of filler components. Still, a faint color flash can be observed, but this effect is similar to the colors seen as the result of natural "strain" which produce a rainbow-like pattern. So experience is necessary for positive detection. The flashes of color seen in a clarity enhanced diamond are one color at a time, whereas the colors produced by strain are spectral in appearance.

These companies specialize in clarity enhancement:

- Oved Diamond Company
- Yehuda Diamond Company
- Koss Diamond

Irradiation to Produce Color Enhancement

Figure 16.2.7***:*** *Unnatural blue/green color produced by irradiation*

The earliest experiments with diamond irradiation date back to 1904, when diamonds were exposed to radium salts, producing a greenish coloration. These early treated diamonds proved to be radioactive, thus posing health concerns to anyone handling them. Diamonds treated with radium salt are occasionally encountered in period pieces of jewelry and should be tested with a Geiger counter as the radioactivity may still linger.
Diamonds can also be bombarded with neutrons from a cyclotron to cause a change in color. The penetration is shallow so only stones that have already been fashioned are treated in this way. Detection of this cyclotron irradiation is quite easy as it produces a color concentration known as the "umbrella effect" The development of nuclear reactors, allowed several diamonds to be treated at a time and the depth of penetration was much greater. This allowed rough diamonds to be treated. The original color produced by treatment was green, but the diamonds could be annealed to produce pink, red, yellow, blue and orange. But these colors are not always stable when subjected to high heat, so care must be taken during repair work, using a torch. It is very difficult to detect this treatment without very sophisticated laboratory equipment.

HPHT-High Pressure High Temperature Treatment

HPHT treatments evolved from early research General Electric conducted in the 1950s in the quest for synthetic diamonds. This process is currently used to remove color from certain diamond classes (Type IIa) or to create fancy colors in Type IIa diamonds in combination with other procedures. The treatment involves subjecting the diamond to heat and pressure similar to those occurring when the diamond initially crystallized. It is claimed that this process "repairs" the crystal lattice, and changes the color. A color change of Z to D has been reported.
HPHT is used in a combination with other treatments to produce fancy colors such as blue, orange, red, green and yellow.
For further information read:

- Gems & Gemology: Lab Notes
- Rapaport News: GIA Confronts Challenge of HPHT
- Bellataire Diamonds: Check F.A.Q.

Synthetics

Swedish and American researchers discovered how to synthesize diamonds in the 1950s. Currently, the two methods used to synthesize diamonds are High Pressure, High Temperature (HTHP) and Chemical Vapour Deposition (CVD).

Diamond synthesis has entered a new phase of development with the expansion of vacuum science and our understanding of molecular physics. At the atomic level, diamond is not unlike pure carbon or graphite in that it can be "built from the ground up." Precipitating diamonds using various Chemical Vapor Deposition techniques has been a slow process up to now. Much of the testing is already done and private labs are now breaking ground at an accelerated pace. What would take 200 hours to precipitate, is now being done in 24 hours.

Types of Synthetics
There are two types of synthetics High Pressure High Temperature (HPHT) and Chemical Vapor Deposition (CVD).
1. HPHT: this type of synthetic is produced by subjecting a piece of graphite to extreme pressure and heat resulting in a stone being produced that is up to one carat in size and the equivalent of SI clarity. The color of stones produced through this technique are generally yellow-orange and yellow-brown and very rarely nearly colorless.

2. CVD: a combination of methane and hydrogen gases are subjected to an existing polished natural diamond, in an environment heated and below normal pressure resulting in the gaseous vapor condensing on the surface of the natural diamond to form a larger synthetic. Synthetics produced by CVD techniques range from nearly colorless to brown.

Detection methods
Physical characteristics: different crystal growth patterns and presence of a seed crystal; hourglass shaped grains; color zoning; lots of inclusions; multiple growth faces of HPHT synthetics leads to a cube-octahedral shaped as opposed to an octahedral shape of natural diamonds. CVD produced synthetics are tabular or block shaped; fluorescent; clouds of white particles located along a plane. Under a microscope: synthetics have lots of inclusions; inclusions located on the girdle; fractures; black spots can be seen in HPHT synthetics as the result of overheating that has lead to graphite fracturing.

Tests:
-Spectroscopic tests such as infrared and UV.
-Cathode luminescence shows cross-like growth sectors in HPHT synthetics.

-Strain patterns are visible under polarized light.
-HPHT phosphorescence (afterglow) once ultraviolet lamps are turned off.
-Fluorescence patterns differ to patterns in natural diamonds. Yellow-green fluorescence in a yellow stone indicates that it is a HPHT synthetic; whereas red fluorescence in a brown or colorless stone highlights that it is a CVD synthetic.

-Magnetic tests find that synthetics can be moved by a powerful magnet whereas diamonds cannot.

Disclosure requirements
- A synthetic must always be disclosed. The use of the word ‘diamond’ can only be used in conjunction with the term synthetic; man-made or artificial.
-Misleading descriptors of synthetics such as ‘cultured’ cannot be used.
- Firms that deal in synthetics can only use terms as listed above in their name.
-Gemological laboratories produce reports for synthetics with the synthetic nature of the diamond fully disclosed.

Simulants

Synthetic cubic zirconia, moissanite, yttrium aluminum garnet (YAG), gadolinium gallium garnet (GGG), strontium titanate, lithium tantalite, lithium niobate, synthetic rutile, leaded crystal (glass imitation).

External links

- Diamonds
- Yellow Diamonds, by Martin Haske
- Growing Diamonds, American Museum of Natural History
- Diamonds at GemologyOnline

Sources

- *Diamanten Fibel* (1991) - Verena Pagel-Theisen ISBN 3980043401
- Gemmology 3rd edition (2005) - Peter Read

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16.03: Corundum

Corundum	
Chemical composition	Al_2O_3
Crystal system	Trigonal
Habit	Prismatic, tabular
Cleavage	None; twinned stones may show parting
Fracture	Conchoidal
Hardness	9
Optic nature	Uniaxial -
Refractive index	1.762-1.770 (+.009,-.005)
Birefringence	0.008-0.010
Dispersion	Low, 0.018
Specific gravity	4
Lustre	Vitreous to Subadamantine
Pleochroism	Weak to moderate



Corundum is an aluminum oxide that occurs in every color of the rainbow. It is allochromatic. When it is red, it is termed ruby. When it occurs in any other color, it is termed sapphire. There are two primary ways that corundum is formed. One is the metamorphosis of limestone and the other is an igneous occurrence in rocks lacking in silica. Since corundum is so hard, it is very resistant to weathering. Therefore, it accumulates in placer gravels. Placer deposits in Sri Lanka at Ratnapura have been mined since before the time of Buddha. The major sources for rubies today are Burma and Madagascar. The major source for sapphire is Madagascar. Other locations include Pakistan, Afghanistan, India, East Africa and Yogo Gulch in Montana.

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16.3.1: Ruby

Ruby

Ruby	
Chemical composition	Al_2O_3
Crystal system	Trigonal
Habit	Prismatic, tabular
Cleavage	None, twinned stones may show parting
Fracture	Conchoidal
Hardness	9
Optic nature	Uniaxial -
Refractive index	1.762-1.770 (+.009,-.005)
Birefringence	0.008-0.010
Dispersion	Low, 0.018
Specific gravity	4
Lustre	Vitreous to subadamantine
Pleochroism	Strong; purplish-red to orangy-red

Ruby is the red variety of the mineral corundum. When corundum occurs in any other color it is referred to as sapphire. Rubies are mined primarily in Burma, Sri Lanka, Thailand, Cambodia, Vietnam, Kenya, Tanzania, Mozambique, Madagascar, India, Afghanistan, and Tajikistan. More important than the gem's locality of origin is the actual color and clarity of the stone. Rubies that are the most valuable will be pure red in color, without any modifying tones of violet, orange or brown and are transparent in clarity. A fine ruby is among the most expensive of any stone in the world.

The brilliant red color of the ruby has given birth to a number of myths and legends. One is that rubies store vast quantities of heat and when placed in water, they will cause the water to boil. Obviously, this is an exaggeration, but some swear if you hold a ruby in your left hand, you'll feel bursts of heat. Ruby, none the less, is a powerful stone and has long been considered a magnet for prosperity, attracting abundance both materially and spiritually.

The word ruby is derived from the Latin *rubeus*, meaning "red".

Diagnostics

Spectrum



Figure 16.3.1.1***:*** *Spectrum of ruby: both natural and synthetic*

UV Fluorescence

The chromium present in ruby causes a natural red fluorescence which is stimulated by both visible and invisible (ultraviolet) light. However, when a ruby contains a significant amount of iron in addition to the chromium, the fluorescence is reduced. Rubies naturally fluoresce stronger to long wave UV than short wave. Stones with the strongest fluorescence are often a pinkish red color in daylight.

Phenomena

- Asterism: 6-rayed stars are common in ruby; rarely, 12-rayed stars have been found.
- Chatoyancy: Although cat's eye rubies have been reported, true cat's eye rubies (where silk forms in a single direction) have not been found.
- Trapiche: Rubies that display a fixed six-spoke pattern of inclusions similar to trapiche emeralds have been found in Mong Hsu, Burma.

Occurrence

The most famous source of fine rubies is Upper Burma, now known as Myanmar. The ruby mines of Myanmar are older than recorded history; Stone Age and Bronze Age mining tools have been found in the mining area of Mogok. Rubies from the legendary mines in Mogok often have a pure red color, which has been described as "pigeon's-blood" although that term is more fanciful than an actual practical standard in the trade today. Myanmar also produces intense pinkish red rubies which are almost electric in color. Many of the rubies from Burma have a strong fluorescence when exposed to ultraviolet rays like those in sunlight. Fine rubies are also found in Myanmar at Mong ('Maing') Hsu and at Nanyazeik (Namya).

Much lesser known are deposits of ruby found in Afghanistan. Although reports of rubies mined in Afghanistan were first chronicled by Marco Polo, the mines have long been shrouded in secrecy and mystery. The mines he referred to are for "balas rubies" (spinels). The actual locality is at Kuh-i-Lal in present-day Tajikistan, just opposite the Afghan border. True ruby is also mined in eastern Tajikistan at Snijnie (aka Snagnyi or Snezhnoye).



Figure 16.3.1.2***:*** *Ruby from Afghanistan*

The crystal above is semi-translucent and heavily included. It can be described as a subhedral ruby crystal nestled in a matrix of white calcite/dolomite marble, dotted with pseudo-hexagonal books of muscovite. It is very strongly fluorescent displaying bright red with LWUV, and weaker red with SWUV.

True rubies are found in Afghanistan at Jegdalek, east of Kabul, which is located in a continental collision zone between the Asian and Indian plates. The deposits occur in metamorphosed limestone (marble) which are found on both plates.

Next to Myanmar, the most important historical source of ruby is Sri Lanka. In modern times, fine rubies have been found along the Thai/Cambodian border between Chanthaburi (Thailand) and Pailin (Cambodia). These deposits were the most important in the world between about 1965 and 1995. Today they are exhausted.

An additional source of ruby is Vietnam. Fine stones have been found at both Quy Chau (along the Lao border) and Yen Bai, north of Hanoi.

East Africa has been a major source of ruby since the 1960's, with a number of sources existing in Kenya, Tanzania, and Mozambique. In addition, Madagascar has a number of ruby deposits of varying importance.

Synthesizing Methods

- Flame fusion (aka Verneuil): This is the most common synthetic ruby.
- Flux melt (Chatham, Kashan, Ramaura, Knischka, Russia)
- Czochralski (pulling)
- Floating zone (Seiko)

Enhancements

Common enhancements to rubies include:

- Heat treatment: This is one of the earliest ruby treatments, and has been performed for over 1000 years. Heating at about 800–1200°C in an oxidizing atmosphere removes the blue tint from ruby, making the stones appear redder. Higher temperature heating (1400–1800°C) can also improve clarity by dissolving rutile silk. Heating in the presence of a flux can artificially heal fissures with tiny quantities of synthetic corundum.
- Bulk ('lattice') diffusion: The diffusion of coloring agents (chromium, in the case of ruby) into the stone via high-temperature heating. Diffusion rates for chromium are very slow; thus only a surface layer of color is found. The same process can diffuse titanium into the stone, producing an artificial asterism.
- Fracture filling: Oil, wax or plastic (with or without dye)
- Lead glass filling: Hides fissures, improves color and increases weight

GIA's Video on Lead Glass Filled Ruby

Sources

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16.3.2: Sapphire

Sapphire	
Chemical composition	Al_2O_3
Crystal system	Trigonal
Habit	Prismatic, tabular
Cleavage	None, may show parting on twinned stones
Fracture	Conchoidal
Hardness	9
Optic nature	Uniaxial -
Refractive index	1.762-1.770 (+.009,-.005)
Birefringence	0.008-0.010
Dispersion	Low, 0.018
Specific gravity	4
Lustre	Vitreous
Pleochroism	Moderate to Strong



Figure 16.3.2.1***:*** *Cornflower Ceylon sapphire*

Sapphire image gallery

Sapphire (a corundum variety) is an aluminum oxide occurring in every color of the rainbow. It is a stone of great hardness and durability. It can also have phenomenal characteristics like asterism (star sapphire) and color changing (like alexandrite). The color changing varieties are mesmerizing, having the ability to change color depending on whether they are viewed in daylight or incandescent light.

The name is derived from the Greek word "sappheiros" meaning "blue". The history of sapphire dates back to at least the 7th

century BC, when they were used by the Etruscans. The sapphires used by the Etruscans, Greeks, and Romans were imported from India (what is now Sri Lanka). Sapphires were reputed to protect kings from harm and envy. In the 13th century, it was written that sapphires had the power to protect against poverty, to make a stupid man wise and an irritable man good-tempered.

Diagnostics

Color

Sapphire occurs in many colors ranging from colorless to black. When a corundum variety is termed "sapphire" it indicates the blue variety. Any other color (except red, which is named ruby) will have a prefix before "sapphire", such as "yellow sapphire".

Causes of color:

- sapphire (blue) - charge transfer between Ti and Fe.

Diaphaneity

Transparent to opaque

Refractometer

Sapphire has a refractive index range between n_ω = 1.767-1.772 and n_ε = 1.759-1.763, with a maximum birefringence of 0.009.
The optic sign is negative like most, naturally occurring, uniaxial gemstones.

Specific gravity

The specific gravity of sapphire is between 3.98 and 4.02 (mean = 4).
It will sink in all common used heavy liquids.

Spectrum

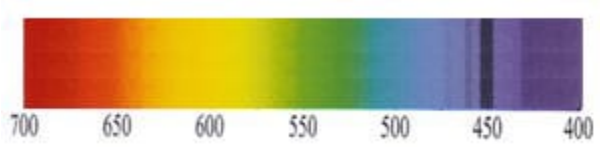


Figure 16.3.2.2***:*** *Spectrum of blue, green and Australian yellow sapphire (high iron content)*

Natural blue, green and yellow sapphires with a high iron content may show the typical "450 complex" as seen in this image. The clear lines at 450 and 460 nm (less sharp than the 450 nm line) will be accompanied with a third (sometimes faint) line at 470 nm. Due to partial absorption of wavelengths between these 450 and 460 nm lines, this whole section may blend together with "smudges" between the lines.
With lesser iron content only the 450 nm line may be observed in natural blue and yellow sapphire. Although this same 450 nm line can also be observed in some blue flame fusion (Verneuil) synthetic sapphire, the "450 complex" has not been reported for synthetic sapphire.

Polariscope

Most natural sapphires are cut with the table almost perpendicular to the optic axis and a uniaxial interference figure should be easily found. Some synthetics (Verneuil type) are cut with the table parallel to the optic axis and the interference figure will be hard to find on the girdle.
Finding an interference figure on the table is not diagnostic.

Phenomena

Asterism

Sapphire may show 6 pointed or 12 pointed stars.
The 6 pointed rays are from reflections on rutile needles that form in directions parallel to the 2nd order prism. 12 pointed rays form from reflections on rutile needles (2nd order prism) and from reflections of hematite-ilmenite needles that lie in the planes parallel to the 1st order prism.

Color change

Cat's-eyes

Trapiche

Synthetics

Flame fusion (Verneuil)

Color change flame fusion sapphire will have a characteristic absorption spectrum with a fuzzy band in the yellow and a diagnostic line at 473 nm (in the blue, called the vanadium line) In some rare cases this 473 line may be seen in natural sapphire.
Curved growth lines are usually seen.

Other synthesizing methods

- Flux melt (Chatham, Ramaura)
- Czochralski pulling process
- Float zone method

Occurrence

Kashmir, Burma, Sri Lanka, Madagascar, Australia, China, Montana USA, Thailand

Enhancements

Common enhancements to sapphire varieties:

- Fracture filling - oil, wax or plastic (with dye or without)
- Lead glass filling - removes crack increases weight
- Diffusion treated - heating causing layer on cut stones - enhance color or produce asterism
- Heat treatment - improves or even changes the color, reduces silk and other impurities
- Irradiation - change colorless stones to yellow - color unstable
- Beryllium treatment - Heated with beryllium as an Additive to produce Orange/yellow/blue colors

A short Film on the Sapphire Mining Techniques in Bang Kacha

Bang Kacha, in Thailand, produces predominately green and golden-orange colored sapphires.
Small quantities of blue sapphires, as well as some star stones, are found here.

A short Film on Sapphire Mining in Ilikaka, Madagascar

A short Film on Sapphire Processing in Sri lanka (ceylon)

This film Shows a trip to the mines of Ratnapura, Pale sapphires of blue and yellow are sorted and heat treated at 1000 C for a few hours to produce White Sapphires. The heat dissolves all silk and Makes the stone whiter and brighter to use as a natural substitute for diamonds.

Sources

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- *Ruby & Sapphire* (1997) - Richard W. Hughes ISBN 0964509768

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16.04: Beryl

Beryl	
Chemical composition	$Be_3Al_2(SiO_3)_6$Beryllium aluminum silicate
Crystal system	Hexagonal
Habit	Prismatic
Cleavage	Very difficult in one direction, rarely seen
Fracture	Conchoidal
Hardness	7.25-7.75
Optic nature	Uniaxial -
Refractive index	1.577-1.583 (+ or - 0.017)
Birefringence	0.005-0.009
Dispersion	Low, 0.014
Specific gravity	2.72 (+0.18,- 0.05)
Lustre	Vitreous to resinous
Pleochroism	Weak to moderate

Beryl is a beryllium aluminum silicate that occurs in every color of the rainbow. When green, it's usually called emerald but there exists green beryl, which is not entitled to be called emerald because its coloring agent is different. When blue, it's aquamarine and when pink, morganite. Yellow is heliodor and colorless is goshenite.
A rare raspberry red variety found in Utah is called bixbite. There is a very rare and costly variety termed Riesling beryl, that can be described as pale green colored with a warm, golden yellow flash. Two unusually dark blue types of beryl have been found as well: Maxixe beryl and True Blue Beryl. Maxixe beryl fades with exposure to light, True Blue Beryl does not.
Beryl has been used as a physician's tool and for gazing stones since ancient times. Those beliefs persist today. Beryl is metaphysically attributed with the ability to cure a number of intestinal and stomach ills, such as nausea, ulcers, and seasickness.

Characteristics

The optical and physical data of beryl can vary between varieties and localities.
Beryl belongs to the beryl group. Pezzottaite (IMA approved in 2003) is also a member of the beryl group.

Genesis

Metamorphic rocks in pegmatites

Localities

Beryl is found in many localities, among them being Brazil, India, Africa, Columbia, Australia, and Pakistan.

Habit

Prismatic with pyramidal and/or pinacoidal terminations. Often vertically striated.

Physical data

Mohs hardness: 7.25 - 7.75 (emerald is brittle).
Specific gravity: 2.7 to 2.9, depending on variety.

Optical data

Refractive index: $n_\varepsilon = 1.56$ $n_\omega = 1.59$, depending on variety.
Birefringence: 0.004 to 0.009, depending on variety.
Optical sign: uniaxial negative.
Dispersion: low, 0.014.
Pleochroism: weak to moderate, strong in "True Blue Beryl" and pezzottaite.

Diaphaneity

Transparent to opaque.

Colors

All varieties of beryl are allochromatic. Main coloring agents are given below.

- Green (emerald), colored by chromium 3^+
- Green (vanadium beryl), colored by vanadium 3^+ - Also known as vanadium emerald
- Green (green beryl), colored by ferric 3^+ and ferrous 2^+ iron
- Green/Yellow (Reisling beryl), unknown coloring agent (most likely iron)
- Blue (aquamarine), colored by ferrous 2^+ Iron
- Blue (Maxixe), colored by color centers
- Blue (True Blue), colored by ferrous 2^+ iron - Trade name for high FeO content aquamarine
- Pink (morganite), colored by manganese 2^+
- Red (bixbite), colored by manganese 3^+
- Yellow (heliodor), colored by ferric 3^+ Iron
- Colorless (goshenite)

Enhancements

Common enhancements to beryl varieties:

- Fracture filling (emerald) - oil, wax or plastic (with dye or without)
- Coatings (emerald) - non-metallic paint or plastic (usually green)
- Heat treatment - improves or even changes the color

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16.4.1: Aquamarine

Aquamarine	
Chemical composition	$Be_3Al_2(SiO_3)_6$Beryllium aluminum silicate
Crystal system	Hexagonal
Habit	Prismatic
Cleavage	Imperfect, basal, almost never seen
Hardness	7.5 to 8
Optic nature	Uniaxial -
Refractive index	1.577-1.583 (+0.017, - 0.017)
Birefringence	0.005-0.009
Dispersion	Low, 0.014
Specific gravity	2.72 (+0.18,-0.5)
Lustre	Vitreous
Pleochroism	Weak to moderate

Aquamarine is a pastel greenish-blue variety of the mineral beryl and owes its color to the presence of iron impurities. Its name is derived from the Latin words for water (aqua) and sea (marine). Crystals form in large hexagonal prisms. In ancient times, it was believed that sailors wearing aquamarine pendants would be protected from the perils of the sea. The stone symbolized happiness and eternal youth. It was viewed in Christian symbolism to bring moderation and control of passions to its owner.

Beauty is in the eye of the beholder

In the past, the natural greenish-blue color of aquamarine was considered the most desirable. Today, the usual color that we see of aquamarine is a pale pastel blue. The most sought after color is a deep blue, as typified by the "Santa Maria", "Santa Maria d'Afrique" and "Marta Rocha" aquamarine finds.

Diagnostics

Aquamarine can be confused with glass, zircon, topaz and synthetic spinel when observed with the trained unaided eye.

Separation aids of aquamarine and its common simulants are given below (all tests should be confirmed by other tests).

Color

Aquamarine is an allochromatic greenish-blue to pale blue variety of beryl, which owes its color to ferrous (2^+) iron (FeO). The higher the iron content, the deeper the color. Only some localities supply the most desired medium to deep blue colors.
Amongst those are True Blue aquamarines from Canada and Santa Maria aquamarines from Brazil.

Loupe

Doubling of pavilion facets may be easily detected in zircon.
Some glass stones are casted and they will show concave facets and rounded facet edges due to shrinkage during cooling down which, however, is not diagnostic since poor (re)polishing of a genuine aquamarine may show this as well.

Polariscope

Aquamarine, topaz and zircon are anisotropic.

Glass and synthetic spinel are isotropic and can be easily separated using the polariscope (ADR can occur).
Topaz is biaxial and can be separated with the use of a conoscope.
Metamict (low-type) zircon may appear isotropic.

Dichroscope

Glass and synthetic spinel will show only one color.
Topaz is trichroic.

Aquamarine will show weak to distinct dichroism (body color and colorless). Zircon has weak pleochroism which may not be seen in heated blue zircon.

"True Blue" aquamarine may show strong dichroism.

Spectroscope

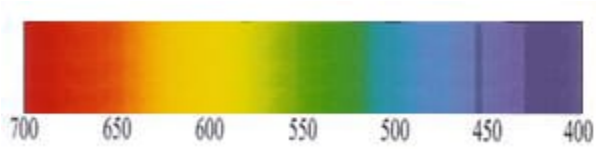


Figure 16.4.1.1***:*** *Spectrum of aquamarine*

Chelsea Colour Filter

The stronger the body color, the stronger the reaction.

Aquamarine	Distinct green
Glass (paste colored by cobalt)	Bright red
Blue synthetic spinel	Orange to red
Blue topaz	Greenish
Blue zircon	Greenish

Refractometer

The refractive indices and optical nature of aquamarine in concert with the body color should leave little doubt about its identity. None of the common simulants will fall in its range.
Typical range for aquamarine is: n_ω = 1.579 - 1.593, n_ε = 1.564 - 1.587 with a birefringence of 0.005 to 0.006.

Specific gravity

Aquamarine will float in bromoform (a heavy liquid with SG = 2.85), while most other pale blue gemstones will sink in it.

Treatments

Routinely heat treated (at approx. 375° C), which removes the green cast, leaving only the blue.

Typical inclusions

Rain inclusions.
Feathers with 2-phase inclusions (typical for pegmatite minerals).
Long parallel channels.

Phenomena

Cat's eye.

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16.4.2: Bixbite

Bixbite	
Chemical composition	$Be_3Al_2(SiO_3)_6$Beryllium aluminum silicate
Crystal system	Hexagonal
Habit	Prismatic
Cleavage	Basal, poor
Fracture	Conchoidal to uneven
Hardness	7.5 - 8
Optic nature	Uniaxial -
Refractive index	1.561 - 1.577
Birefringence	0.004 - 0.009
Dispersion	Low, 0.014
Specific gravity	2.63 - 2.72
Lustre	Vitreous
Pleochroism	Weak



Bixbite (or "red beryl") is the allochromatic orange-red to purplish-red variety of beryl which owes its color to manganese (Mn) impurities.
Physical and optical properties may be slightly higher than usual beryl properties.

Bixbite was named after Maynard Bixby of Utah, USA.
Locations where this rare mineral is found include Utah and New Mexico, USA.

Bixbite is rarely free from inclusions (most are heavily included) and stones above 3ct. are scarce.

Red (bixbite) and pink (morganite) beryls are now manufactured using the hydrothermal process by Biron International in Australia, by ANICS in Japan and by Novosibirsk in Russia. The coloring agent in these synthetics is titanium and/or cobalt, opposed to larger quantities of manganese in their natural counterparts.
The pleochroism in these synthetics is usually medium to strong whereas it would be weak in natural red beryl. The distinguishing factor for the hydrothermal synthetic red beryls is inhomogeneous growth patterns seen under magnification.

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16.4.3: Emerald

Emerald	
Chemical composition	$Be_3Al_2(SiO_3)_6$Beryllium aluminum silicate
Crystal system	Hexagonal
Habit	Prismatic
Cleavage	Imperfect, basal
Fracture	Conchoidal to uneven
Hardness	7.5 (brittle)
Optic nature	Uniaxial -
Refractive index	1.566 - 1.600
Birefringence	0.004 - 0.010
Dispersion	Low, 0.014
Specific gravity	2.67 - 2.78
Lustre	Vitreous
Pleochroism	Weak to distinct



Figure 16.4.3.1

Diagnostics

The trained eye should have little trouble recognizing an emerald due to its silky rich green color. The main challenge, however, is distinguishing natural emerald from the various types of synthetic emerald.

Color

Emerald is the chromium-bearing variety of beryl with a "grass green" primary hue and a slight yellow or blue secondary hue. The

purer the green, the finer the quality of the stone. In 1960, H. Espig described the color of emerald as " .. warmen Grün einer Wiese im Frühling .." (warm green of a meadow in spring).

There are two other varieties of beryl that are also green, vanadium beryl and green beryl. Vanadium beryl is also known as "vanadium emerald" and can exhibit colors like the chromium-bearing cousin, but is usually much less included. It should be noted that there are two schools of thought on whether the vanadium-colored emeralds are entitled to be called emerald. "Green beryl" is a pale green beryl that shows more resemblance to aquamarine and is colored by iron. One will hardly ever confuse green beryl with emerald -- unless you are at the selling end of the market.

Tsavorite garnet is a gemstone that comes close to emerald in color but has a much "harder" color than the chromium-colored emeralds.

Magnification

Emerald is classed as a "Type III" in the GIA clarity grading system. This means that these stones are commonly included, and the inclusions are mostly visible to the trained eye. Only a few emeralds are "eye clean".
In general, eye-visible inclusions in emerald are forgiven if the stone shows good color and transparency overall.

With a 10x loupe or a microscope at low magnification, typical inclusions are seen which often give vital clues about the stone's origin, being it locality or natural/synthetic.

Optical and physical properties

The optical and physical properties of emerald vary with location. Synthetic emeralds usually have lower values.
n_ω = 1.575 - 1.600, n_ε = 1.566 - 1.588 for natural emerald and n_ω = 1.560, n_ε = 1.565 for synthetic emerald.
Birefringence of natural emerald ranges from 0.004 to 0.010, while synthetic emerald will hardly ever go over 0.004.

The specific gravity of synthetic emerald is slightly to distinctively lower than that of natural stones. Natural emeralds will sink more rapidly in a heavy liquid of SG = 2.65 (bromoform diluted with toluol). Hydrothermal synthetics have a higher SG than flux melt synthetics. The hydrothermal synthetics can be separated from natural emeralds by the lower birefringence.

Source	Refractive Index	Birefringence	Specific gravity
Australia	1.570-1.579	0.005 - 0.007	2.67 - 2.70
Austria	1.591-1.584	0.007	2.72 - 2.76
Brazil	1.566 - 1.575	0.005	2.68 - 2.70
Colombia	1.568 - 1.586	0.006	2.69 - 2.71
India	1.585 - 1.593	0.007	2.73 - 2.74
Pakistan	1.588 - 1.600	0.007	2.75 - 2.78
South Africa	1.586 - 1.593	0.007	2.75
Tanzania	1.578 - 1.585	0.007	2.74
Zambia	1.580 - 1.590	0.004 - 0.010	2.71 -2.76
Zimbabwe	1.586 - 1.593	0.007	2.73 - 2.77
Hydrothermal synthetic	1.560 - 1.563	0.003	2.67 - 2.69
Flux synthetic	1.560 - 1.565	0.003 - 0.004	2.65 - 2.66

Spectroscope

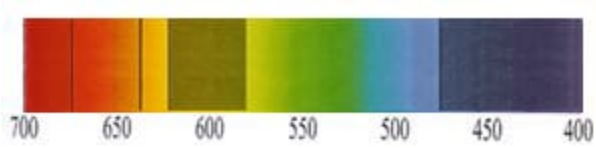


Figure 16.4.3.2***:*** *Spectrum of fine emerald*

Natural chromium-bearing emeralds will usually show a distinct spectrum with a doublet in the red, two lines in the orange-red region and a weak band in the yellow part.
Synthetic emerald shows the same absorption pattern with the addition of a line in the blue (at 477 nm). However, this line may also be seen in fine quality natural emerald.

It should be noted that emerald is known to show different absorption spectra along the ordinary and the extraordinary vibrational directions.

Chelsea Colour Filter

The Chelsea Colour Filter was designed to discriminate between emerald and its simulants in the 1930s, primarily to detect chromium in Colombian and Siberian emeralds. Over the years, it lost that usefulness because of the arrival of synthetic emeralds. As synthetic emeralds are also colored by chromium, this tool is no longer very reliable. This is especially true now we know that vanadium and iron may also be an emerald's coloring agent as well.

The chromium will cause fluorescence in natural daylight, but the iron content that is present in emeralds from certain locations dulls or totally suppresses that. Hence, there will be a different (not red) reaction to the Chelsea Filter.
In the past, it was suggested that if an emerald would light up bright red under the CF, the stone would either be of Colombian origin or be synthetic. In other words, all synthetics will show up bright red due to rich chromium content. This is no longer viable, as iron may be introduced into the synthesizing process to mimic a more natural fluorescence reaction.

The use of the "Emerald Filter" set may be useful as an addition to the Chelsea Colour Filter.

Treatments

Enhancement of emerald to mask inclusions is regarded as routine. About 90% of all emeralds on the market have undergone some kind of treatment.
Most common enhancements are oiling, waxing or impregnation with materials that have a RI close to that of emerald. Opticon is a brand name for one substance used to impregnate emerald. In Columbia, cedarwood oil is utilized in the treatment process to minimize the appearance of fissures and other inclusions which impair the clarity of the emeralds.

Phenomena

While very rare, cat's eye emeralds do exist. Another phenomenon, found in Colombian emeralds, is the trapiche emerald which displays a six-armed, fixed star. This is not to be confused with asterism.

Synthetics

Emerald can be synthesized by different methods. The most common synthetic emeralds on the market today are of hydrothermal and flux-melt origin. The coloring agents of synthetic emerald vary by manufacturer.

Manufacturer	Method	Coloring agent
Chatham	Flux melt	Cr

Igmerald	Flux melt	Cr, Ni (+ Fe)
Gilson	Flux melt	Cr, Ni (+ V, Fe, Cu)
Biron	Hydrothermal	Cr and V

Imitations

Most simulants of emerald, such as tsavorite and glass, should be easily detected with the unaided trained eye. There are unfortunately also doublet and triplet imitations on the market that may be similar in appearance to emerald.

Ron Ringsrud Takes Us to the Emerald Mines of Colombia

Sources

- *Gems Their Sources, Descriptions and Identification* 4th Edition (1990) - Robert Webster/ B.W. Anderson
- Secrets of the Gem Trade, by Richard Wise
- *A Student's Guide to Spectroscopy* (2003) - Colin H. Winter
- *Gem Identification Made Easy* 3rd edition (2006) - A.C. Bonanno/ Antoinette Matlins
- *The colour of Igmerald* .. - Dr. Karl Schmetzer/Dr. Lore Kiefert - The Journal of Gemmology, July 1998

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16.4.4: Vanadium Beryl

Emerald	
Chemical composition	$Be_3Al_2(SiO_3)_6$Beryllium aluminum silicate
Crystal system	Hexagonal
Habit	Prismatic
Cleavage	Imperfect, basal
Fracture	Conchoidal to uneven
Hardness	7.5 (brittle)
Optic nature	Uniaxial -
Refractive index	1.566 - 1.600
Birefringence	0.004 - 0.010
Dispersion	Low, 0.014
Specific gravity	2.67 - 2.78
Lustre	Vitreous
Pleochroism	Weak to distinct



Figure 16.4.4.1***:*** *Brazilian vanadium emerald*

There are two schools of thought concerning whether green beryl colored by vanadium should be considered an emerald. The GIA considers it to be so, Gem-A does not. Up until about 40 years ago, no one considered vanadium beryl to be an emerald, despite known deposits such as those in Afghanistan and Pakistan. The Chelsea Colour Filter was developed specifically to separate emerald from vanadium beryl, as the chromium content in an emerald will make it appear red under the filter while the vanadium stones are inert.

In the early 1960s, large deposits of vanadium beryl were discovered in Brazil. Much to the frustration of the miners and dealers, the industry refused to consider this material as emerald due to its lack of chromium content. In 1963, the GIA issued its first lab report identifying vanadium colored green beryl as emerald. In their curriculum, they now teach that vanadium beryl is emerald.

However, this was not accepted by the entire industry. Whether they are or aren't still depends on to whom you are talking or on where you are doing your studies.

Vanadium emeralds tend to be less included than their chromium-colored brethren.

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16.4.5: Goshenite

Goshenite	
Chemical composition	$Be_3Al_2(SiO_3)_6$Beryllium aluminum silicate
Crystal system	Hexagonal
Habit	Prismatic
Cleavage	Poor, basal
Fracture	Conchoidal to uneven
Hardness	7.5
Optic nature	Uniaxial -
Refractive index	1.57 - 1.59
Birefringence	0.004 - 0.009
Dispersion	Low, 0.014
Specific gravity	2.7 - 2.9
Lustre	Vitreous
Pleochroism	None



Figure 16.4.5.1***:*** *Colorless Goshenite*
Xuebaoding, Pingwu, Sichuan Province, China

Goshenite is the colorless variety of beryl and is named after Goshen in Hampshire County, Massachusetts, USA (one of the localities where this gem is found).

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16.4.6: Green Beryl

Green Beryl	
Chemical composition	$Be_3Al_2(SiO_3)_6$Beryllium aluminium silicate
Crystal system	Hexagonal
Habit	Prismatic
Cleavage	Imperfect, basal
Hardness	7.5
Optic nature	Uniaxial -
Refractive index	1.564 - 1.593
Birefringence	0.005-0.006
Dispersion	Low, 0.014
Specific gravity	2.68-2.72
Lustre	Vitreous
Pleochroism	Weak to distinct

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16.4.7: Heliodor

Heliodor	
Chemical composition	$Be_3Al_2(SiO_3)_6$Beryllium aluminum silicate
Crystal system	Hexagonal
Habit	Prismatic
Cleavage	Poor, basal
Fracture	Conchoidal to uneven
Hardness	7.5
Optic nature	Uniaxial -
Refractive index	1.57 - 1.58
Birefringence	0.004 - 0.009
Dispersion	Low, 0.014
Specific gravity	2.7 - 2.9
Lustre	Vitreous
Pleochroism	Weak to moderate (shades of body color)

Heliodor is the golden yellow or golden green variety of the mineral beryl. It is a beryllium aluminum silicate. The golden color is produced when iron replaces some of the aluminum in the crystal structure. Heliodor can contain trace amounts of uranium, making it slightly radioactive. Heliodor was discovered in Namibia in 1910 in a pegmatite that also produced aquamarine, which is also colored by iron.

Crystals form very distinct hexagonal prisms that are some of the largest crystal examples in gemology. The largest faceted heliodor, 2,054 carats, is on display at the Smithsonian Institution in Washington D.C.

The name heliodor is Greek, meaning "gift from the sun". This stone is not often used in jewelry because it lacks brilliance and fire. Heliodor is found in Minas Gerais and Goias in Brazil, in Ukraine in Russia, and also in Connecticut and Maine in USA.

Heliodor is considered a talisman for those named Hugh.

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16.4.8: Maxixe

Maxixe beryl	
Chemical composition	$Be_3Al_2(SiO_3)_6$Beryllium aluminum silicate
Crystal system	Hexagonal
Habit	Prismatic
Cleavage	Poor, basal
Fracture	Conchoidal to uneven
Hardness	7.5
Optic nature	Uniaxial -
Refractive index	1.579 - 1.592
Birefringence	0.007
Dispersion	Low, 0.0014
Specific gravity	2.69 - 2.8
Lustre	Vitreous
Pleochroism	Distinct

Maxixe (pronounced Mah-she-she) is the almost-sapphire color variety of beryl. It was discovered in 1917 in the Maxixe mine in the Piaui area south of Arassuahy, Minas Gerais, Brazil. Maxixe owes it's very unstable color due to natural irradiation that causes a color center most probably in the NO_3 sites. When exposed to sunlight or temperatures above 100° C, it will rapidly lose its color. Color can be restored by irradiation (gamma, x-ray or neutron) and annealing.
As of around 1970, some dark-blue beryls started appearing on the market again and research showed that the color was also due to irradiation (artificial), but the color center, in this case, proved to be in the CO_3 sites. This new type was named "Maxixe-type" beryl and, like Maxixe, it is a very unstable color. The original color of these beryls was yellow or green.
There are also bi-colored Maxixe-type beryls (yellow/blue). Their color is attributed to artificial irradiation on specimens that have an uneven distribution of impurities.

The impurities found in Maxixe and Maxixe-type beryl are Cs, Zn, Li, Rb, B and high concentrations of Fe.

As the color is mainly caused by a color center, this is not an aquamarine beryl but a variety on its own.
Both the nitrate and carbonate varieties can be irradiated by natural and artificial means, and their distinction is not possible with standard gemological instruments. Therefore, Kurt Nassau suggested dropping the Maxixe-type nomenclature and name both Maxixe.

Maxixe and Maxixe-type beryl have stronger dichroic colors in the ordinary ray, while aquamarine has the stronger dichroic color in the extra-ordinary ray. Classification based on this is not viable, as heliodor may also have the stronger dichroic color in the ordinary ray. Thus it is not a characteristic feature of Maxixe beryl.

Sources

- *On the identification and fade testing of Maxixe beryl ..* - Kurt Nassau, The Journal of Gemmology (April 1996)

Additional Information on Maxixe Beryl

- http://www.mindat.org/min-10019.html
- http://www.minsocam.org/ammin/AM61/AM61_100.pdf

Found material on a bi-color maxixe beryl:

- www.gaaj-zenhokyo.co.jp/researchroom/kanbetu/2004/kan_2004_02en.html

Deposit reported in 2003 in the Yukon: but this article mentions they weren't sure if it were maxixe:

- www.cbc.ca/health/story/2003/08/28/gem_rare030828.html

GIA article:

- http://gia.metapress.com/content/17u210387m035644/fulltext.pdf

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16.4.9: Morganite

Morganite	
Chemical composition	$Be_3Al_2(SiO_3)_6$Beryllium aluminium silicate
Crystal system	Hexagonal
Habit	Prismatic
Cleavage	Poor, basal
Fracture	Conchoidal to uneven
Hardness	7.5
Optic nature	Unixaial -
Refractive index	1.58 - 1.60
Birefringence	0.008 - 0.009
Dispersion	Low, 0.014
Specific gravity	2.80 - 2.90
Lustre	Vitreous
Pleochroism	Weak to moderate (shades of body color)



Figure 16.4.9.1***:*** *Minas Gerais, Brazil*

Morganite is the pink, peach or lilac variety of the mineral beryl. It is a beryllium aluminum silicate colored with a trace amount of manganese. The stone was named after the American banker and gem lover, J. P. Morgan, shortly after it was first discovered in 1902 in the Malagasy Republic (Madagascar). Fine examples are currently found in Minas Gerais, Brazil, and Madagascar.



Figure 16.4.9.2***:*** *Minas Gerais Brazil*

Red (bixbite) and pink (morganite) beryls are manufactured using the hydrothermal process by Biron International in Australia. The coloring agent in these synthetics is titanium opposed to manganese in their natural counterparts.

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16.4.10: Riesling

Riesling beryl	
Chemical composition	$Be_3Al_2(SiO_3)_6$Beryllium aluminum silicate
Crystal system	Hexagonal
Habit	Prismatic
Cleavage	Poor, basal
Fracture	Conchoidal to uneven
Hardness	7.5
Optic nature	Uniaxial -
Refractive index	1.59
Birefringence	0.004 - 0.009
Dispersion	Low, 0.014
Specific gravity	2.66 -2.86
Lustre	Vitreous
Pleochroism	Strong

Riesling beryl was first discovered by a German geologist in 1840 near a small village in East Germany, but unfortunately, the amount they found was small. The bulk of the material was cut and given to royalty as gifts or sold to private collectors at the time. (The majority of the stones are thought to have stayed in Germany, although some particularly fine specimens were thought to have gone to the British Royal Family as gifts). This link to royalty is one of 4 key components in the pricing this stone.

This stone is actually a pale green color, with a warm golden yellow flash. It is strongly dichroic (green-yellow), which is a second key pricing component as this is unusual in beryl.

It also has a refractive index of 1.59 which is high for precious beryl and is the third key component in pricing. It makes an attractive, sparkly cut stone. (As with all beryl, it is a 7.5 on the Mohs Scale, SG 2.66-2.86)

As there was so little of the material available, it disappeared quickly and was not found again until November 2002, so its rarity is the fourth main pricing component.

At that date, the Everhart family (originally from Germany themselves) found it in Vale of Jequitinhonha near Arcuaii in Brazil. The family was mining for morganite and came across greenish golden stones that were initially thought to be hiddenite. Testing proved them to be beryl.

Still only a small pocket of stones, the rough was exhausted and sent to Italy to sell and exhibit. Remaining rough was sold in the US for cutting and distribution. Some dealers still have material available, but they are very hard to come by. A second pocket, larger than the first Brazilian find, was found in March 2004 but it still produces relatively small amounts of material.

The Jequitinhonha mines produce Riesling beryl as well as pale green and pale golden green. However, it is only the strongly dichroic stones that are considered real Riesling beryl, and it is only these stones that fetch the high prices.

Some collectors recognize only the German material as true Riesling. The only way to be sure from an investment perspective is to obtain a stone with a known provenance. It is difficult but doable. Any good German dealer with a fine reputation will be able to get you one within a week, but the price may be high.

Acknowledgments

- Martin H. Read
- Mindat[1]

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16.4.11: True Blue

True Blue beryl	
Chemical composition	$Be_3Al_2(SiO_3)_6$Beryllium aluminum silicate
Crystal system	Hexagonal
Habit	Prismatic
Cleavage	Poor, basal
Fracture	Conchoidal to uneven
Hardness	7.5
Optic nature	Uniaxial -
Refractive index	1.57 - 1.59
Birefringence	0.004 - 0,009
Dispersion	Low, 0.014
Specific gravity	2.69
Lustre	Vitreous
Pleochroism	Distinct (shades of body color)

Discovered in the Yukon, Canada in 2004. An exceptionally dark blue aquamarine, whose color is the result of an extremely high concentration of iron. Unlike the Maxixe beryl, the color is photostable, which means that it is resistant to fading.

True Blue Beryl is a trade name for medium to dark blue aquamarine from Canada, marketed by True North Gems.

External links

- True North Gems
- Mineralogical and geochemical study of True Blue Aquamarine .. (pdf format)

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16.4.12: Pezzottaite

Pezzotaite	
Chemical composition	Cesium Beryllium Lithium Aluminium Silicate $Cs(Be_2Li)Al_2Si_6O_{18}$
Crystal system	Trigonal
Habit	subhedral-to-euhedral hexagonal tabular
Cleavage	imperfect (basal)
Fracture	conchoidal to irregular
Hardness	8
Optic nature	uniaxial -
Refractive index	1.601-1.620
Birefringence	0.011
Dispersion	unknown
Specific gravity	3.04-3.14
Lustre	vitreous
Pleochroism	moderate to strong

Pezzottaite image gallery

Pezzottaite is a raspberry-red to pink member of the Beryl Group named after Dr. Federico Pezzotta. Discovered in Madagascar and IMA approved in 2003 as a new mineral.

Although related to Beryl it is not a variety of Beryl, it is a gem quality member of the Beryl Group to which also Beryl belongs.

Crystallography

Pezzottaite has trigonal symmetry. Pezzottaite with Cs and Li is not isostructural with beryl but the arrangement is close. Pinacoid, prism, pyramid are common forms. Etching and corrosion is seen.

Chemical composition

Composition with trace elements: Pezzottaite is $Cs(Be_2Li)Al_2Si_6O_{18}$; i.e. Cs, Li rich beryl. In Beryl three Be atoms as in formula occupy three symmetrical positions but in pezzottaite, the three positions are occupied in an ordered pattern by Be_2Li rather than Be_3. Thus these positions are not related by symmetry and changes to 3-fold symmetry rather than hexagonal and larger unit cells. This increase has an effect on the properties to a great extent. Other important traces include Rb, Na, Mn, K, Sc, Ti, Fe also.

Beryl: $Be_3Al_2Si_6O_{18}$
Pezzottaite: $Cs(Be_2Li)Al_2Si_6O_{18}$

Diagnostics

Color

Due to radiation induced color center involving Mn3+; Purplish pink, sometimes orangish tinge present (Madagascar).

Magnification

Inclusions: Growth tubes, fractures, fingerprint and fluid inclusions with phase. Transparent near colorless crystals. Also transparent green crystals of tourmaline. Rarely color zoning.

Phenomena

Cat's eye

Treatments

Fracture filling with oil or resin.
Heat may lighten color and irradiation darken it.

Simulants

- Morganite (lower heft, lower R.I)
- Tourmaline (Doubling of inclusions & Back facet edges, Higher birefringence)
- Tourmaline cat's eye is very close to pezzottaite cat's eye (Birefringence blink and inclusions)

Occurrence

Geological occurrence: Granitic pegmatites having Li, Cs, Ta and other rare Earth elements. Mainly crystallized from the fluids in the cavities as late-stage crystals.

Geographical occurrence: Sakavalana pegmatite in Madagascar; little in Afghanistan too and sometimes in other granitic pegmatites.

Sources

- *Gems and Gemology* 2003 - GIA
- *Journal of Gemmology* - Gem-A

External links

- Pezzottaite
- Pezzottaïte: "Béryl" rose-pourpre atypique riche en Césium de Madagascar (in French)

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16.05: Quartz

Quartz	
Chemical composition	SiO_2 Silicon dioxide
Crystal system	Trigonal
Habit	Prismatic
Cleavage	Poor
Fracture	Conchoidal
Hardness	7
Optic nature	Uniaxial +
Refractive index	1.544 - 1.553
Birefringence	0.009
Dispersion	0.013
Specific gravity	2.65
Lustre	Vitreous
Pleochroism	None



Figure 16.5.1***:*** *Quartz crystal cluster specimen*
Sinai, Egypt

Quartz is a common variety of silicon dioxide that often crystallizes into well-formed hexagonal prisms. It occurs in many colors, including purple amethyst, yellow citrine, and a smoky variety, referred to as smoky quartz or cairngorm. Colorless, transparent quartz crystals represent the modern concept of "crystal".

Crystal balls with a truly mystic significance are always made from quartz. Quartz crystals are among the earliest talismans. Examples of rock crystal objects date back to 75,000BC. Every culture on the planet has attributed magical powers to quartz crystals.
The Japanese considered it "the perfect jewel", symbolizing patience and perseverance, the infinity of space and purity. Native

Americans used quartz crystals as a hunting talisman and "fed" them with deer blood. Crystal balls, credited with the ability to cure diseases, were brought to Europe from the Near East by the Crusaders. In Scotland and Ireland, farmers used crystal balls to keep livestock healthy.

Diagnostics

Crystalline quartz (especially rock crystal) can be confused with many other gemstones such as topaz, scapolite, danburite, phenakite, and others. Usually, a refractometer reading will eliminate most of them.
Scapolite has properties close to quartz, but has a negative optic sign.

Color

- Rock Crystal - colorless
- Smokey Quartz - smokey brown
- Amethyst - violet
- Citrine - yellow
- Ametrine - violet/yellow
- Prasiolite - green
- Rose Quartz - rose

Diaphaneity

Transparent to opaque.

Polariscope

Only two minerals that are commonly used as gemstones have a uniaxial character with a positive optic sign, quartz, and zircon. Some others are phenakite, cinnabar, synthetic moissanite, and some idocrase.
In addition, crystalline quartz will usually show a "bulls-eye" due to enantiomorphism. When one encounters a conoscopic interference figure with a bulls-eye, it can be nothing else than quartz.
Or in the case of quartz with Brazil twinning (as amethyst) it will show quadruple Airy Spirals.

With the addition of a quarter wave plate one can observe if the specimen is left or right-handed quartz, or both. The double Airy Spirals will either spiral to the left or to the right, indicating left or right-handedness.

Refractometer

Quartz will show fairly constant readings with $n_\omega = 1.544$ and $n_\varepsilon = 1.553$, the full birefringence is 0.009.
Optic character: uniaxial +.

Other minerals falling in this range:

- Scapolite - Uniaxial with a negative optic sign
- Iolite - Biaxial optic character
- Feldspar - Biaxial optic character

Specific gravity

The s.g. of quartz is 2.65 and it suspends in bromoform diluted with toluol.

Magnification

- "Tiger stripe" inclusions
- ribbon like reddish inclusions

- ball or drop-shaped opaque inclusions
- 2-phase inclusions
- 3-phase inclusions
- negative crystal inclusions
- angular zoning in amethyst, citrine and smokey quartz

References

- *Quartz* (1987) - Michael O'Donoghue ISBN 0408014628

See also

- Chalcedony

External links

- Twinned natural quartz versus twinned synthetic quartz (in French)

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16.5.1: Amethyst

Amethyst	
Chemical composition	Silicon dioxide SiO_2
Crystal system	Trigonal
Habit	Prismatic
Cleavage	Poor
Fracture	Conchoidal
Hardness	7
Optic nature	Uniaxial +
Refractive index	1.544 - 1.553
Birefringence	0.009
Dispersion	Low, 0.013
Specific gravity	2.63 - 2.65
Lustre	Vitreous
Pleochroism	Weak to strong

Amethyst image gallery

Amethyst is a purple variety of the mineral quartz. It occurs in all intensities of the color purple from a light pastel to a depth of royal splendor. Until the beginning of the 20th century, it was quite rare and costly. When vast deposits were found in Brazil, amethyst became very accessible and affordable. Amethyst has always been linked to the thinking process, ensuring clarity of vision. It inspires creativity, courage, and valor. Amethyst has been successfully synthesized in the lab, so buyers need to be sure their source is qualified to separate natural from lab-grown material.

Magnification

Amethyst is a type I stone in the GIA clarity grading system is usually free from eye visible inclusions. Typical inclusions visible with magnification are:

- liquid feathers "fingerprints" (also known as "tiger stripes" or zebra stripes")
- 2-phase, 3-phase inclusions
- negative crystals

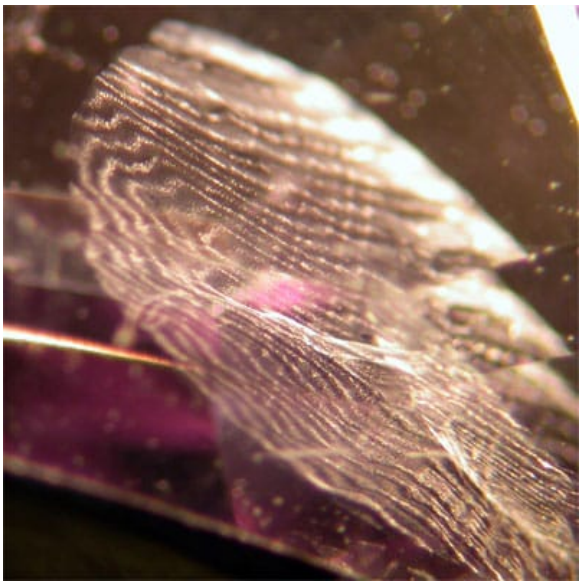


Figure 16.5.1.1***:*** *classic "fingerprint" inclusion*
30X Magnification
By Barbra Voltaire

Polariscope

With the use of a polariscope, one can find the typical "bull's eye" for quartz, but that can be seen in both twinned natural stones as in many twinned synthetics.

To discern the hydrothermal (twinned) synthetics from natural amethyst one must look at the interference figures of the stone without a conoscope. In natural, twinned, amethyst one will see a pattern known as "Brewster fringes". This can be seen when looking down the optic axis of the gem and on lateral rotation, this pattern quickly disappears. With the twinned hydrothermal stones these fringes are not seen in the typical triangular form, rather they follow the outline of the stone. On lateral rotation, this image will be in view much longer. This method works in most cases, for the remaining 1% to 3% one will need to infrared spectrometry to discern between the two.

Immersion in a liquid and magnification might aid greatly in spotting the "Brewster fringes".

G&G Articles on Amethyst 1934-1980

The GIA has published all the G&G's from 1934 until 1980 online. The organization of the list by subject was done by Joseph Gill.

- Winter 1949, **Amethyst color induced in rock crystal via cyclotron**, p. 255, 1p.
- Winter 1963, **A very rare star amethyst**, p. 101, 2pp.
- Summer 1971, **Inclusions in amethyst that look like space capsules**, p. 322, 2pp.
- Winter 1977, **Synthetic Amethyst from Russia**, p. 365, 2pp
- Winter 1978, **Synthetic Amethyst**, p. 365, 2pp.
- Spring 1979, **Synthetic Amethyst, currently no test for a flawless amethyst**, p. 151, 3pp.
- Summer 1980, **Citrine-Amethyst Quartz - A Gemologically New Material**, by John I. Koivula, p. 290, 4pp.
- Winter 1980, **More News On Citrine-Amethyst Quartz**, by John I. Koivula, p. 409, 1p.

References

- Notari F., Boillat P.-Y., Grobon C. (2001), Quartz alpha-SiO2: Discrimination des améthystes et des citrines naturelles et synthétiques, Revue de Gemmologie AFG, N° 141/142, pp. 75-80.

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16.5.2: Ametrine

Ametrine	
Chemical composition	Silicon dioxide SiO_2
Crystal system	Trigonal
Habit	Prismatic
Cleavage	Poor
Fracture	Conchoidal
Hardness	7
Optic nature	Uniaxial +
Refractive index	1.544 - 1.553
Birefringence	0.009
Dispersion	0.013
Specific gravity	2.63 - 2.65
Lustre	Vitreous

Ametrine is a variety of quartz that contains both amethyst and citrine sectors in the same crystal.

Ametrine is only found in one mine in the world. The Anahi Mine in Bolivia is the major world producer of ametrine. The mine first became famous in the 17th century. A Spanish conquistador received it as a dowry when he married a princess from the Ayoreos tribe named Anahi. Ametrine was introduced to Europe through the conquistador's gifts to the Spanish queen.

In the gemology world, ametrine was originally described as a curious find in 1980. (Hehar, Koivula, Vargas, 1980). Its locality was originally given as Rio Grande do Sul in Brazil, but later determined to be in Bolivia. The material met with immediate suspicion, as Kurt Nassau had a synthetic example of amethyst/citrine in his collection for several years prior to the "find" in 1980.

Several unsuccessful tests were conducted in order to see if this bi-colored quartz was actually the result of a series of treatments. Then, it was discovered that specimens of a specific sectored amethyst from Minas Gerais, which exhibited alternating sections of dark and light amethyst, could indeed be altered to ametrine. This was done with a succession of heat treatments followed by irradiation coupled with subsequent annealing. (Gems & Gemology, Spring 1981).

The results of this experimentation made "naturally occurring ametrine" suspect and controversial at best. Ametrine, in the '80s, was presumed to be 100% the result of treatment.

That all changed when the Anahi Mine in Bolivia was shown to produce vast quantities of naturally occurring ametrine, (insert egg on face), in the early 90's. Between 1989-1994, 100 tons of naturally occurring ametrine xls were extracted from the Anahi Mine. (G&G, Spring 94).

This is a valuable lesson for gemologists.
We must be careful when extrapolating experimental evidence.
Just because something CAN be done, does not mean it IS being done.

As mentioned earlier, there were examples of bi-colored, synthetic, amethyst/citrine in existence in the '70s, but it was not until 1994 that Russian synthetic ametrine was available for commercial distribution. These crystals were being produced by hydrothermal growth from alkaline solutions. We are able to separate the synthetic material from natural on the basis of growth features (twinning and color zoning), sophisticated EDXRF chemical analysis and IR spectral analysis. (G&G Summer 1999)

External links

- Ametrine from Caltech

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16.5.3: Citrine

Citrine	
Chemical composition	Silicon dioxide SiO_2
Crystal system	Trigonal
Habit	Prismatic
Cleavage	Poor
Fracture	Conchoidal
Hardness	7
Optic nature	Uniaxial +
Refractive index	1.544 - 1.553
Birefringence	0.009
Dispersion	Low, 0.013
Specific gravity	2.63 - 2.65
Lustre	Vitreous
Pleochroism	Weak to distinct

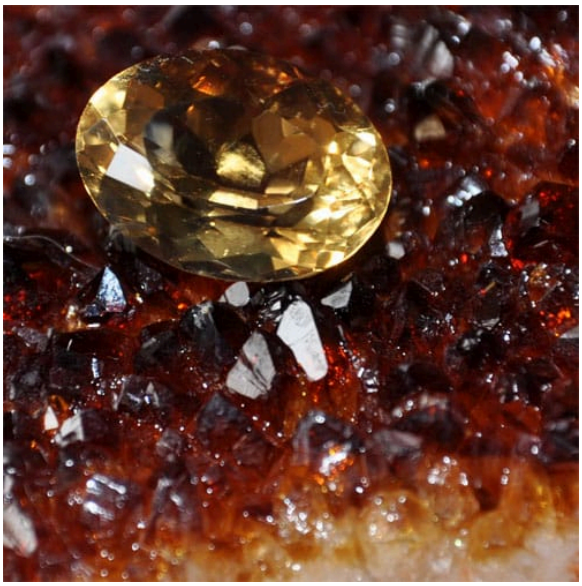


Figure 16.5.3.1***:*** *Citrine oval faceted on Madiera Citrine Crystals.*
Photo courtesy of Barbra Voltaire

Citrine is a yellow or golden variety of quartz. Most citrine available today is heat-treated amethyst. When amethyst is heated to about 482.2 degrees Celsius, it alters to a golden tone. Citrine has been credited with curing urinary tract infections, jaundice and kidney ailments. This is obviously a color association.

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16.5.4: Prasiolite

Prasiolite	
Chemical composition	SiO_2 Silicon dioxide
Crystal system	Trigonal
Habit	Prismatic
Cleavage	Poor
Fracture	Conchoidal
Hardness	7
Optic nature	Uniaxial +
Refractive index	1.544 - 1.553
Birefringence	0.009
Dispersion	0.013
Specific gravity	2.63 - 2.65
Lustre	Vitreous
Pleochoism	Weak to strong



Figure 16.5.4.1***:*** *Brazil*

Prasiolite is the green variety of quartz.
The color is caused by the heating of either natural occurring amethyst (by exposure to sunlight or artificial) or by artificial heat treatment of irradiated amethyst. The former will give a more stable green color that is less prone to fading.

Synonyms: Prasiolita, greened amethyst, green quartz.
Misnomers: Green amethyst.

The name "prasiolite" should not be confused with prasolite (a green variety of the chlorite group) and praseolite which is the green variety of cordierite.

Diagnostics

Chelsea Colour Filter

Reactions under incandescent light:

Irradiated green quartz: red.
Heat treated green quartz: green.

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16.5.5: Rock Crystal

Rock Crystal (Colorless Quartz)	
Chemical composition	SiO_2 Silicon dioxide
Crystal system	Trigonal
Habit	Prismatic
Cleavage	Poor
Fracture	Conchoidal
Hardness	7
Optic nature	Uniaxial +
Refractive index	1.544 - 1.553
Birefringence	0.009
Dispersion	Low, 0.013
Specific gravity	2.65
Lustre	Vitreous
Pleochroism	None



Figure 16.5.5.1***:*** *Quartz crystals from the personal collection of Barbra Voltaire*

Rock Crystal is the common name for colorless quartz. The material is abundant and has been used for centuries as a gem. Quartz crystals are among the earliest talismans. Examples of rock crystal objects date back to 75,000BC. Every culture on the planet has attributed magical power to quartz crystals. The Ancient Greeks prized rock crystal and believed it to be water frozen by the gods to a state of perpetual solidity. They carved the material into seals and intaglios. The Japanese considered it "the perfect jewel", symbolizing patience and perseverance, the infinity of space and purity. Native Americans used quartz crystals as a hunting talisman and "fed" them with deer's blood.



Figure 16.5.5.2***:*** *70mm Crystal Ball*

Crystal balls were brought to Europe from the Near East by the Crusaders. They were credited with the ability to cure diseases. In Scotland and Ireland, farmers used crystal balls to keep livestock healthy. Today, crystal balls are still used for mystical divination, gazing and New Age healing. They vary in size ranging from small beads measuring a few millimeters in diameter to the largest known crystal ball in existence. It is displayed at the Smithsonian Institution in Washington, D.C. It is called the "Warner Crystal Ball." This specimen has a weight of 48.5 kilograms and a diameter of 32.5 centimeters.

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16.5.6: Rose Quartz

Rose Quartz	
Chemical composition	SiO_2 Silicon dioxide
Crystal system	Trigonal
Habit	Prismatic
Cleavage	Poor
Fracture	Conchoidal
Hardness	7
Optic nature	Uniaxial +
Refractive index	1.544 - 1.553
Birefringence	0.009
Dispersion	0.013
Specific gravity	2.63 - 2.65
Lustre	Vitreous
Pleochroism	Weak to strong

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16.5.7: Sunset Quartz

Sunset Quartz	
Chemical composition	SiO_2 Silicon dioxide
Crystal system	Trigonal
Habit	Prismatic
Cleavage	Poor
Fracture	Conchoidal
Hardness	7
Optic nature	Uniaxial +
Refractive index	1.544 - 1.553
Birefringence	0.009
Dispersion	0.013
Specific gravity	2.65
Lustre	Vitreous
Pleochroism	None

Sunset quartz is a variety of quartz in very limited supply. It was discovered in 2006 in Minas Gerais, Brazil, with the vein producing only 5 kg. of gem quality material total. The collection pictured above, belonging to Karim Moussally, is one of the largest personal collections in existence.
The yellowish and orange color of the quartz is the result of microscopic acicular (needle-like) inclusions.



Figure 16.5.7.1***:*** *Acicular Incusions in Sunset Quartz: 40X*
Photo courtesy of Barbra Voltaire

Analysis of these inclusions, reported in **Gems & Gemology** in Winter 2006, determined that they were **NOT** rutile as we might have suspected but were composed of Si, Al and Fe with traces of K! The identification of the actual mineral was inconclusive, but it has been speculated that it could possibly be acicular limonite.

The material is semi-transparent to translucent with a milky consistency.
The RI, Birefringence, SG (see template on the right) is typical of quartz.

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16.5.8: Smokey Quartz

Smoky Quartz	
Chemical composition	SiO_2 Silicon dioxide
Crystal system	Trigonal
Habit	Prismatic
Cleavage	Poor
Fracture	Conchoidal
Hardness	7
Optic nature	Uniaxial +
Refractive index	1.544 - 1.553
Birefringence	0.009
Dispersion	0.013
Specific gravity	2.65
Lustre	Vitreous
Pleochroism	Weak to moderate

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16.06: Quartz - Polycrystalline

Microcrystalline means that the crystals are not recognizable with the naked eye or with a standard microscope.

Minerals made up from even smaller crystals are said to be cryptocrystalline from the Greek word 'Kruptos' meaning hidden and are classed as being massive in their habit because they have no orderly structure. Most are semi-transparent to opaque.

With modern day microscopes with high magnification power, these terms don't seem valid anymore and are referred to as polycrystalline.

Includes stones classified as varieties of the quartz species:

- chalcedony
- aventurine quartz
- hawk's eye
- prasiolite
- quartz cat's eye
- rose quartz
- tiger's eye

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16.6.1: Chalcedony

Chalcedony	
Chemical composition	Silicon dioxide SiO_2
Crystal system	Trigonal
Habit	Aggregate
Fracture	Conchoidal
Hardness	6.5-7
Refractive index	1.535 - 1.539
Specific gravity	2.60
Lustre	Vitreous

Chalcedony is microcrystalline (cryptocrystalline) quartz. The name is often used to encompass all varieties of microcrystalline quartz such as jasper, carnelian, chrysoprase, and bloodstone. The mineral is very abundant and found all over the world. The most common variety is a muted blue-gray tone (unnamed) found in geodes and vugs.

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16.6.1.1: Agate

Agate	
Chemical composition	Silicon dioxide SiO_2
Crystal system	Trigonal
Habit	Aggregate
Fracture	Conchoidal
Hardness	6.5-7
Refractive index	1.535 - 1.539
Specific gravity	2.60
Lustre	Vitreous

Agate is a variety of banded microcrystalline quartz, or chalcedony. There are countless varieties of agate usually named after their physical characteristics or location of origin. The layers of agate form as layers of chalcedony line a cavity (or vug) in a host rock. Since the 12th century, agate has been attributed with the power of improving one's disposition as well as their eyesight. These beliefs still carry on today. One claim for agate was stated in The Book of Saxon Leechdoms written in 1864, where it was written that agate prevents harm from thunder, sorcery, demonic possession, poison, and drunkenness!

Varieties

Moss Agate

This variety is called "moss" agate because of the inclusions (chlorite, clays, various oxides/hydroxides, etc.) in transparent/translucent chalcedony. The final effect makes the stone resemble "moss". Depending on the inclusions the moss can show different colors, with green/brown and red as the most common. They usually take a good polish and make attractive stones.

Priday Moss Agate, Oregon



Figure 16.6.1.1.1***:*** *Moss Agate from a Priday thunderegg (Oregon). Green moss.*



Figure 16.6.1.1.2***:*** *Detail of a Moss Agate from a Priday thunderegg (Oregon).*



Figure 16.6.1.1.3***:*** *Detail of a Moss Agate from a Priday thunderegg (Oregon).*

Moss Agate (from 'thunderegg')



Figure 16.6.1.1.4***:*** *Moss Agate from Oregon, red moss.*



Figure 16.6.1.1.5***:*** *Moss Agate from Oregon, red moss, detail.*



Figure 16.6.1.1.6***:*** *Moss Agate from Oregon, red moss, detail.*

Cathedral Agate

The "Cathedral agate" is found in Mexico and features red and gold moss/plumes in a light purplish or white agate with very fine fortification (typical banding pattern).

Cathedral Agate, Mexico



Figure 16.6.1.1.7***:*** *Mexican Cathedral Agate cab*

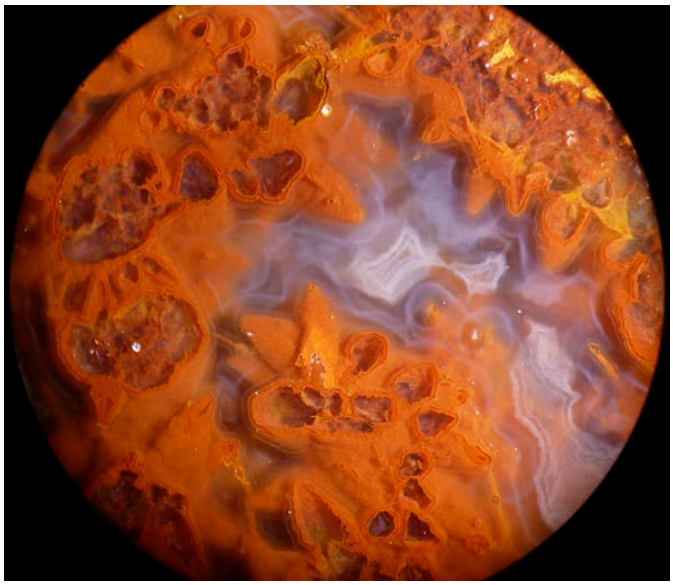


Figure 16.6.1.1.8***:*** *Cathedral agate, detail of the red moss/plumes and purplish agate fortification*



Figure 16.6.1.1.9***:*** *Cathedral agate, slab.*

Crazy Lace Agate

This agate comes from Chihuahua, Mexico. This agate shows a very fine banding, often with striking and contrasting colors. Another interesting fact about this kind of agate is that the banding often grows parallel to the surfaces of the crystals that were present before the crystallization/deposition of the agate (usually calcite, quartz, zeolites). The presence of these layers provides very interesting patterns in the slabs and in the finished cabochons.

Crazy Lace Agate, Mexico



Figure 16.6.1.1.10***:*** *Crazy Lace Agate cabochon*



Figure 16.6.1.1.11***:*** *Photomicrograph showing the fine banding ("fortification")*



Figure 16.6.1.1.12***:*** *A slab of Crazy Lace Agate showing the typical structure of this material*

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16.6.1.2: Arkansas stone

Arkansas stone is a polycrystalline, silica (chalcedony) rich chert that is often used as a whetstone. Bench jewelers often use this stone as a sharpening tool for gravers. Very fine-grained stones are used to give a high polish to the sharp edges of a tool, making them even sharper.
Appraisers use the black, opaque variety as a touch stone to determine the quality of precious metals (in conjunction with acids). The mineralogical name of this rock is novaculite.

The specific gravity of the material varies with grit size and ranges from approx. 2.2 to 2.5.
Novaculite is found in Arkansas, Texas, and Oklahoma (all USA).

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16.6.1.3: Bloodstone

Agate	
Chemical composition	Silicon dioxide SiO_2
Crystal system	Trigonal
Habit	Aggregate
Fracture	Conchoidal
Hardness	6.5-7
Refractive index	1.535 - 1.539
Specific gravity	2.60
Lustre	Vitreous

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16.6.1.4: Carnelian

Carnelian	
Chemical composition	Silicon dioxide SiO_2
Crystal system	Trigonal
Habit	Aggregate
Hardness	6.5 - 7
Refractive index	± 1.54
Specific gravity	2.55 - 2.70
Lustre	Vitreous



Figure 16.6.1.4.1***:*** *Carnelian cabochon*

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16.6.1.5: Chrysoprase

Chrysoprase	
Chemical composition	Silicon dioxide SiO_2
Crystal system	Trigonal
Habit	Aggregate
Hardness	6.5 - 7
Refractive index	± 1.54
Specific gravity	2.55 - 2.70
Lustre	Vitreous



Figure 16.6.1.5.1***:*** *Chrysoprase Cabochon*
Photo courtesy of Rick Martin

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16.6.1.6: Jasper

Jasper	
Chemical composition	SiO_2 Silicon dioxide
Crystal system	Trigonal
Habit	Aggregate, massive
Fracture	Conchoidal
Hardness	6.5-7
Refractive index	1.53-1.54
Specific gravity	2.58-2.64
Lustre	Vitreous



Figure 16.6.1.6.1***:*** *Imperial Jasper Cabochon, Mexico*
Photo courtesy of Rick Martin

Scenic Jasper

Picture, or scenic, or landscape jasper and agate gets its name from the pictures of scenes, animals or objects formed by the colorful patterns from other minerals present.

Poppy Jasper

"Poppy Jaspers" are jaspers showing red orbicular patterns resembling poppies, hence the name. The best varieties come from Northern California, close to the S. Andreas Fault system (Morgan Hill and Guadalupe).

Guadalupe Poppy Jasper, California



Figure 16.6.1.6.1***:*** *Guadalupe poppy jasper cab.*



Figure 16.6.1.6.2***:*** *Guadalupe poppy jasper cab.*

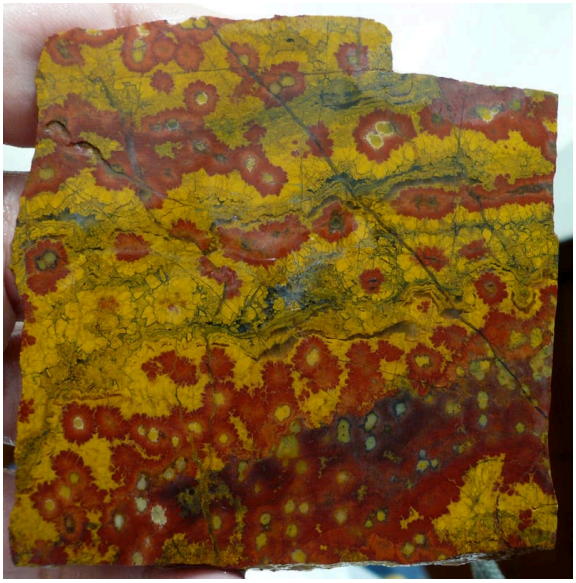


Figure 16.6.1.6.3***:*** *Guadalupe poppy jasper slab.*

Morgan Hill Poppy Jasper, California



Figure 16.6.1.6.4***:*** *Morgan Hill poppy jasper cab.*



Figure 16.6.1.6.5***:*** *Morgan Hill poppy jasper. Details of the orbicular structures.*



Figure 16.6.1.6.6***:*** *Morgan Hill poppy jasper slab.*

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16.6.1.7: Onyx

Agate	
Chemical composition	SiO_2 Silicon dioxide
Crystal system	Trigonal
Habit	Aggregate
Fracture	Conchoidal
Hardness	6.5-7
Refractive index	1.535 - 1.539
Specific gravity	2.60
Lustre	Vitreous

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16.6.1.8: Sard

Agate	
Chemical composition	SiO_2 Silicon dioxide
Crystal system	Trigonal
Habit	Aggregate
Fracture	Conchoidal
Hardness	6.5-7
Refractive index	± 1.54
Specific gravity	2.60
Lustre	Vitreous

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16.6.1.9: Sardonyx

Sardonyx	
Chemical composition	SiO_2 Silicon dioxide
Crystal system	Trigonal
Habit	(edit me)
Cleavage	Poor
Fracture	Very brittle, conchoidal
Hardness	7
Optic nature	(edit me)
Refractive index	1.544 - 1.553
Birefringence	0.009
Dispersion	0.013
Specific gravity	2.65
Lustre	Vitreous
Pleochroism	None

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16.6.1.10: Tigereye

Agate	
Chemical composition	SiO_2 Silicon dioxide
Crystal system	Trigonal
Habit	Aggregate
Fracture	Conchoidal
Hardness	6.5-7
Refractive index	± 1.55
Specific gravity	2.60
Lustre	Vitreous



Figure 16.6.1.10.1

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16.07: Zoisite

Zoisite	
Chemical composition	Calcium aluminum silicate
Crystal system	Orthorhombic
Habit	Prismatic and massive
Cleavage	Perfect, prismatic
Fracture	Uneven
Hardness	6.5
Optic nature	Biaxial +
Refractive index	1.685-1.707
Birefringence	0.008
Dispersion	Low, 0.012
Specific gravity	3.35
Lustre	Vitreous
Pleochroism	Strong in blue



Figure 16.7.1**:** *Zoisite with ruby bead*

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16.7.1: Tanzanite

Tanzanite	
Chemical composition	Calcium aluminum silicate
Crystal system	Orthorhombic
Habit	Prismatic
Cleavage	Perfect, prismatic
Fracture	Uneven
Hardness	6.5
Optic nature	Biaxial +
Refractive index	1.685-1.707
Birefringence	0.008
Dispersion	Low, 0.012
Specific gravity	3.35
Lustre	Vitreous
Pleochroism	Strong trichroism (dichroism in heated)

Tanzanite, a variety of zoisite, was discovered in the Merelani district of Tanzania near Mount Kilimanjaro in 1967. So far, all tanzanite discovery has been limited to a six-kilometer strip in this area, which was divided into four blocks, labeled A, B, C and D. Block C is the only site still commercially producing rough tanzanite at this time.

Almost all purple and blue varieties of the stone are the result of heat treatment. The stone is a yellowish-brown "bug juice" color when it is mined, but when heated to between 426.7-482.2 degrees Celsius, it becomes that gorgeous violet blue that is used in jewelry. The stone has never been found in another locality, so it is indeed a depleting resource. It is somewhat soft (6-7 on Mohs scale of hardness) and has a direction of cleavage along which it can be easily broken. It is desirable because of its elegant, opulent color.

Diagnostics

Tanzanite can be confused with sapphire. Interference figure, refractive index, and specific gravity can easily separate tanzanite from sapphire.

Color

Violet blue to blue to bluish purple. The color is due to vanadium.
Someone once described the color of tanzanite as "Tanzanite looks like sapphire wishes it could look" [Wise, 2003].

Diaphaneity

Transparent.

Magnification

Tanzanite is a type I stone on the GIA clarity scale and is usually not included.

Refractometer

n_α = 1.685 - 1.696, n_β = 1.693 -1.702 and n_γ = 1.700 -1.707 with a birefringence of 0.008 - 0.013.
The optic nature is biaxial +.

Other stones falling in this range are:

- Diopside (higher birefringence)
- Sinhalite (higher birefringence)
- Idocrase (higher refractive index and lower birefringence)

Specific gravity

3.25 - 3.60 (mean 3.35).
Tanzanite will sink slowly in methylene iodide (sg = 3.33).

Spectroscope

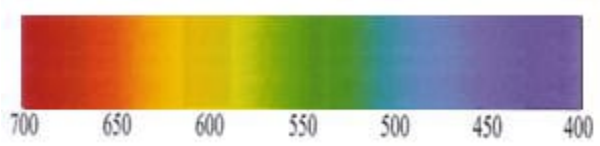


Figure 16.7.1.1***:*** *Spectrum of blue, transparent tanzanite.*

Untreated tanzanite will show weak bands in the yellow-orange, red, green and blue. Heat treated tanzanite may show even weaker bands or none at all (especially in lighter colors).

Pleochroism

Natural tanzanite does occur and it exhibits strong trichroism. The typical colors are violet to purplish red, blue and green (the green portion may also be yellow).
Most tanzanite on the market is heated brownish zoisite and shows two distinct colors under the dichroscope: violet to purplish red and blue. There will be two shades of blue, so the stone is still considered as trichroic, but the yellow or green is not observed in these heated stones. For that reason, it is often referred to as being dichroic.

Durability

Tanzanite is relatively soft on the Moh's scale (6½) so care should be taken not to scratch it. Due to its perfect prismatic cleavage it can easily break when hit with a hard and/or sharp object.

Phenomena

Cat's eye stones are known to exist.

Treatments

Usually, Tanzanite is heat treated to remove the yellow-green to brown components. Heating is usually conducted at temperatures between 400 and 600 degrees centigrade. As Tanzanite's color largely depends on the ratio of Vanadium and Titanium within its crystal structure, any changes to this delicate balance have a marked effect on its color. Heating results in a valence exchange reaction or redox reaction which causes an increase in the violet and blue colors and renders the Titanium colorless. The image below shows Tanzanite crystals before and after heating.

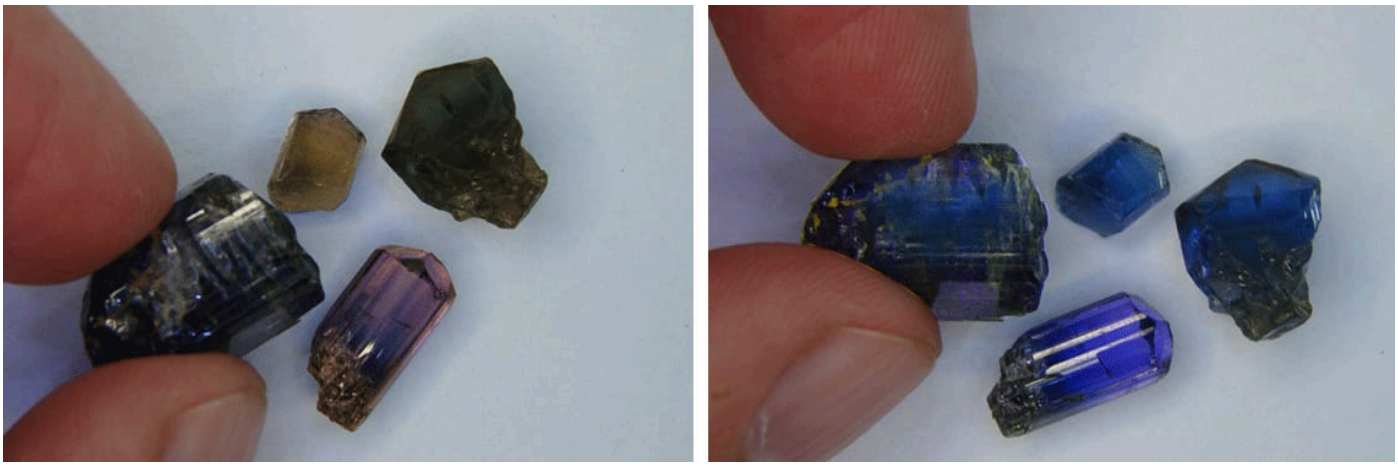


Figure 16.7.1.2

Tanzanite pictures



Figure 16.7.1.3***:*** *Rought Tanzanite showing burgundy color, untreated, directly in Mirerani.*



Figure 16.7.1.4***:*** *Tanzanite ore is bluish, graphite-containing, often with quartz, pyrite, garnet*

Synthetics

None known (although there are rumors of a synthetic tanzanite being created in Russia).

Imitations

Most stones that are used to simulate tanzanite can easily be separated by optical properties and/or the use of a Hanneman Tanzanite Filter.

Table 16.7.1.1

Imitation	
Synthetic forsterite	
U.M.Tanzanic (lead glass)	
Coranite™ (synthetic sapphire)	
Tanavyte™ (YAG)	
Tanzation (synthetic spinel/cobalt glass triplets)	
Cubic zirconia	

Sources

- *Gem Identification Made Easy, Third Edition* (2003) - Antoinette L . Matlins, Antonio C. Bonanno ISBN 0943763347
- Gemmology 3rd edition (2005) - Peter Read

- Gems Their Sources, Descriptions and Identification *4th Edition (1990) - Robert Webster (6th ed.)*
- *A Students' Guide to Spectroscopy* (2003) - Colin Winter FGA, DGA ISBN 0954485300
- *Gem Reference Guide* (1995) - GIA ISBN 0873110196
- Secrets of the Gem Trade, by Richard W. Wise
- Insider Gemologist: What Are the Identifying Characteristics of Tanzanite, and How Is It Distinguished from Imitations? (2004) - GIA

- The Science Behind Tanzanite Heating (2013) - Antony Zagoritis, GG

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16.7.2: Thulite

Thulite	
Chemical composition	Calcium aluminum silicate
Crystal system	Orthorhombic
Habit	Massive
Hardness	6.5
Optic nature	Biaxial +
Refractive index	1.685-1.707
Birefringence	0.008
Dispersion	Low, 0.012
Specific gravity	3.35
Lustre	Vitreous

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16.08: Garnet

Garnet	
Chemical composition	$L_3M_2(SiO_4)_3$somorphous series
Crystal system	Cubic
Habit	Dodecahedra
Cleavage	None
Hardness	6.5-7.5
Optic nature	Isotropic
Refractive index	1.74-1.89
Birefringence	None
Specific gravity	3.60-4.20
Lustre	Vitreous to sub-adamantine

Chemical composition

Garnet is the family name given to a group of members with a common crystal habit and slightly different chemical makeup (isomorphous). The following are the 6 endmembers of the garnet group:

- Pyrope (magnesium aluminum silicate)
- Almandine (iron aluminum silicate)
- Spessartite (manganese aluminum silicate)
- Uvarovite (calcium chromium silicate)
- Grossular (calcium aluminum silicate)
- Andradite (calcium iron silicate)

In total, there are 15 members of the garnet group. In gemology, we traditionally disregard the other 9 because they do not produce gem quality minerals.

All the above members are rarely found with an ideal chemical makeup. Instead, they form an isomorphous series. Most gem quality garnets belong to either of the following 5 isomorphous series [Hanneman,2000] and their chemical composition is an intermediate between the two endmembers mentioned.

- Pyrope-Almandine
- Pyrope-Spessartite
- Spessartite-Almandine
- Pyrope-Grossular
- Grossular-Andradite

According to whether the L or the M component in the chemical composition of the species is constant, we can divide the members of the garnet family into two groups.

- Pyralspites (**Pyr**ope, **Al**mandine, **Sp**essart**ite**)
- Ugrandites (**U**varovite, **Gr**ossular, **And**rad**ite**)

Classification of gem garnets

No other gemstone gives rise to so much controversy as the species of the garnet group.
The garnet group consists mainly of isomorphous series with end members that never occur in its pure form in nature. This makes

it almost impossible to assign definite values of physical and optical properties to each species.
The major gemological institutes (GIA and Gem-A), as well as the Mineralogical Society, seem to be in disagreement about when a garnet should be named a pyrope, an almandine, or a pyrope-almandine.

Traditionally, mineralogists use the 50%-50% rule. If there is over 50% of pyrope in the chemical composition, it will be a pyrope and vice versa. They do not recognize the intermediate values of the isomorphous series. It is either a pyrope or an almandine, never a pyrope-almandine [Hanneman, 2000]. In gemology, we do accept the latter.

The physical and optical properties of the members of the garnet group are therefore not to be taken too literally until a clear, unified system of naming gem garnets is accepted worldwide.
The physical and optical properties given are not definite values; they overlap.

Specific gravity is in general not regarded as a primary means of separation between species of the garnet group. The combination of color (eye and spectroscopy) with RI however is.
The table below gives the refractive indices taught currently (2006) by the two major gemological institutes compared to Dr. Hanneman's unified system of classifying garnets.

Table 16.8.1***:*** *Refractive indices of gem garnets*

	Hanneman	Gem-A	GIA
Pyrope	1.714-*	1.74-1.76	1.720-1.770
Almandine	*-1.830	1.76-1.81	1.760-1.820
Spessartite	*-1.800-*	1.79-1.82	1.790-1.814
Grossular	*-1.734-*	1.73-1.75	1.730-1.760
Andradite	*-1.887	±1.89	1.855-1.895
* depending on isomorphous series			

An in-depth study on garnets has been carried out by Carol M. Stockton and Dr. D. Vincent Manson at the GIA laboratory in the 1980s which resulted in a final paper on the classification of gem garnets in 1985. In this final paper gem quality garnets were divided into 8 species according to chemical and physical properties, viz. grossular, andradite, pyrope, pyrope-almandine, almandine, almandine-spessartine, spessartine, and pyrope-spessartine.
Qualifications were made on color, refractive index and spectral analyses (supported by chemical analyses).

Table 16.8.2***:*** *Refractive indices according to Stockton and Manson*

Species	Refractive index	Hues	Varieties
Grossular	1.730-1.760	Green through reddish-orange, colorless	Tsavorite, hessonite
Andradite	1.880-1.895	Very slightly yellowish green through orangy yellow	Demantoid, topazolite
Pyrope	1.714-1.742	Purplish red through reddish orange, colorless	Chrome pyrope
Pyrope-almandine	1.742-1.785	reddish orange through red-purple	Rhodolite
Almandine	1.785-1.830	Orange red through purplish red	
Almandine-spessartine	1.810-1.820	Reddish orange through orange-red	

Spessartine	1.780-1.810	Yellowish orange through reddish orange	
Pyrope-spessartine	1.742-1.780	Greenish yellow through purple	Malaia, color change

During the study, Stockton and Manson published 4 earlier, intermediate, articles in Gems & Gemology which grabbed the attention of Dr. Hanneman. Although the Stockton/Manson papers brought great new insights into the classification of garnets in gemology, Hanneman proposed a system that is perhaps more easily understood by gemologists.
It should be noted that any classification system is under debate and the reader should make the decision on which system is most appropriate/logical.

Dr. Hanneman believes the classification of garnets should be based on the 30-70% rule instead of the 50-50% rule mineralogists use. This system is similar to that used for plagioclase feldspar, with the note that garnets can form series with all (or most) members of the garnet group instead of a static system between two end members.
As the differences between the two end members differ, so will the 30% and 70% of each "timeline", hence lowering or raising the values. Thus, instead of assigning a definite value (or a range of values) to a particular species, the values are flexible and are directly related to the isomorphous series the species belongs to.
This seems to be a complicated system, yet it could provide for a very good alternative to the vague values assigned to gem garnets as described in textbooks and syllabuses today while giving room for varieties (marketable names) such as rhodolite, malaia, and future discoveries.

Table 16.8.3***:*** *Refractive indices according to Hanneman*

Series	Name (species)	Refractive index	Varieties
Pyrope-Almandine	Pyrope	1.714-1.749	
	Pyrope-Almandine	1.749-1.795	Rhodolite
	Almandine	1.795-1.830	
Pyrope-Spessartite	Pyrope	1.714-1.740	
	Pyrope-Spessartite	1.740-1.774	Malaia (malaya)
	Spessartite	1.774-1.800	
Almandine-Spessartite	Spessartite	1.800-1.809	
	Almandine-Spessartite	1.809-1.821	Mandarin, Kashmirine, Hollandine
	Almandine	1.821-1.830	
Grossular-Almandine	Grossular	1.734-1.763	
	Grossular-Almandine	1.763-1.801	
	Almandine	1.821-1.830	
Grossular-Spessartite	Grossular	1.734-1.754	Tsavorite, Hessonite
	Grossular-Spessartite	1.754-1.780	
	Spessartite	1.780-1.800	
Pyrope-Grossular	Pyrope	1.714-1.720	
	Pyrope-Grossular	1.720-1.728	

	Grossular	1.728-1.734	
Grossular-Andradite	Grossular	1.734-1.770	
	Grossular-Andradite	1.770-1.841	Grandite
	Andradite	1.841-1.887	Melanite, Topazolite, Demantoid

Hanneman's concept illustrated

The concept of intermediate species between endmembers is not new and has been earlier proposed by Anderson and Stockton/ Manson. Following is an illustration according to Hanneman's calculations.



Figure 16.8.1***:*** *Timeline illustration for Hanneman's concept of the Pyrope-Almandine series (in % almandine)*

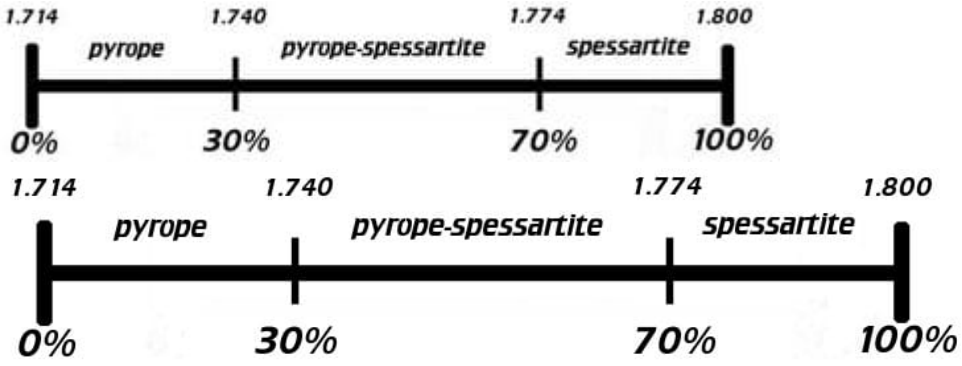


Figure 16.8.2***:*** *Timeline illustration for Hanneman's concept of the Pyrope-Spessartite series (in % spessartite)*

On the left are "timeline" examples of two isomorphous series with flexible values. Pyrope will have an RI range of 1.714-1.749 in the pyrope-almandine series, while having 1.714-1.740 in the pyrope-spessartite series.

It is unlikely that this system will ever be adopted by the major gemological institutes (in fact, they have rejected it) yet it does provide us with some insight in the complexity of trying to create a universal system for garnet classification.

Some of the intermediate species (such as pyrope-almandine) are already accepted by both Gem-A and the GIA, but not all schools. Rhodolite and malaia garnet are (or will probably be) given "species" instead of "variety" status by the GIA.

Valency in isomorphous replacement

The chemical formula of garnet is $L_3M_2(SiO_4)_3$, which means that the first element has a valency of 2^+ and the second element has a valency of 3^+. Elements with the same valency can easily replace each other to form new chemical bonds, as in the case of garnet. One should not confuse the presence of trace elements with isomorphous replacement. Trace elements are not part of the "ideal" chemical makeup.

Related topics

- Isomorphous replacement

G&G Articles on Garnet 1934-1980

The GIA has published all the G&G's from 1934 until 1980 online. The organization of the list by subject was done by Joseph Gill.

- Spring 1968, **A ruby red 4.27 ct. chrome pyrope**, p. 279, 1p.
- Winter 1968, **Transparent green grossularite**, p. 375, 1p.
- Spring 1969, **Tanzanian garnets**, p. 15, 2pp.
- Summer 1969, **Emerald-green grossularite garnet**, p. 58, 1p.
- Summer 1969, **A 2-phase inclusion in garnet (first seen)**, p. 67, 2pp.
- Winter 1969, **A fine 6 ct. demantoid garnet showing horsetail inclusions**, p. 121, 2pp.
- Spring 1970, **New transparent green grossularite inclusions**, p. 151, 2pp.
- Spring 1970, **Alexandrite-like garnet from Tanzania**, p. 162, 1p.
- Summer 1970, **A rare Alexandrite Garnet from Tanzania**, p. 174, 4pp.
- Summer 1970, **Spessartite garnet inclusions**, p. 189, 1p.
- Summer 1970, **Spessartite absorption spectrum**, p. 197, 2pp.
- Summer 1970, **Grossularite garnet inclusions**, p. 196, 2pp.
- Fall 1970, **Testing demantoid with ultra-violet light**, p. 226, 2pp.
- Fall 1970, **New transparent colorless grossularite from Tanzania**, p. 227, 3pp.
- Fall 1970, **Alexandrite garnet from Norway**, p. 229, 1p.
- Fall 1971, **A massive hydrogrossular garnet cut in cabochon** (one end pink, the other end green) (showing absorption spectrum), p. 354, 3pp.
- Summer 1972, **Two unusual rhodolite property variations**, p. 40, 1p.
- Spring 1973, **A typical demantoid inclusion**, p. 150, 1p.
- Summer 1974, **Green grossularite garnets, "tsavorites" on the Kenya-Tanzania border**, p. 290, 6pp.
- Summer 1974, **Composition of "tsavorites" from Kenya and Tanzania**, by Switzer, p. 296, 2pp.
- Fall 1974, **Jewelry repair involving garnet and glass doublets**, dangerous, p. 344, 2pp.
- Fall 1974, **Some unusual inclusions in hessonite and rhodolite**, p. 349, 2pp.
- Winter 1978, **Blue to Red Colour Changing Garnet from East Africa**, p. 122, 2pp.
- Winter 1978, **Demantoid garnet from Korea; Alexandrite garnet from East Africa**, p. 123, 3pp.
- Summer 1979, **Colorless and Green Grossularite from Tanzania**, by Pieter Muije, p. 162, 12pp.
- Fall 1979, **Unusual Gem Garnets of East Africa**, p. 218, 2pp.

References

- *Naming Gem Garnets* (2000) - W.Wm. Hanneman, Ph.D
- *A Proposed New Classification for Gem Quality Garnets* - Stockton & Manson, Gems & Gemology Winter 1985, pp205-217

External links

- Schematic overview of the garnet group (doc format)

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16.8.1: Almandine

Almandine Garnet	
Chemical composition	$Fe_3Al_2(SiO_4)_3$ron aluminum silicate
Crystal system	Cubic
Habit	Dodecahedra
Cleavage	None
Hardness	7.5
Optic nature	Isotropic
Refractive index	1.78-1.81
Birefringence	None
Specific gravity	3.95 - 4.20
Lustre	Vitreous

Diagnostics



Figure 16.8.1.1***:*** *Oval, faceted Almandine garnet*

Color

Brownish red, red to violet/purple

Spectroscope

Almandine has a typical iron spectrum.

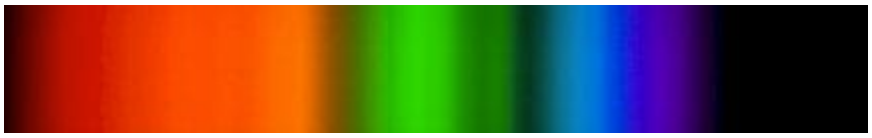


Figure 16.8.1.2***:*** *usually at 504, 520, and 573nm, may also have faint lines at 423, 460, 610 and 680-690nm*

Inclusions

- Short rutile needles in 3 directions
- Crystals surrounded by stress cracks
- Irregular and rounded crystals

Polariscope

Almandine is isotropic but may have a small DR.

Specific gravity

Almandine sinks in all common heavy liquids.

Optical effects

Almandine may show asterism and chatoyancy.

Varieties

Rhodolite

Rhodolite is the purple (pinkish/violet) variety of pyrope-almandine.

Localities

India, USA, Brazil

Occurrence

Metamorphic rocks

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16.8.2: Andradite

Andradite Garnet	
Chemical composition	$Ca_3Fe_2(SiO_4)_3$alcium Iron Silicate
Crystal system	Cubic
Habit	Dodecahedra
Cleavage	None
Hardness	6.5
Optic nature	Isotropic
Refractive index	1.85-1.89
Birefringence	None
Specific gravity	3.85
Lustre	Vitreous to adamantine

Diagnostics

Color

Green, yellow-green and black.

Inclusions

- Fine curving asbestos fibres in a radiating pattern ("horse-tail") in demantoid.

Refractometer

With an RI of about 1.89, the readings are outside the limit of the standard gemological refractometer.

Specific gravity

Sinks in all common heavy liquids.

Chelsea Color Filter

Demantoid appears reddish or pinkish.

Spectroscope

Demantoid has a specific pattern due to iron and chromium.

Dispersion

The dispersion in andradite garnets is high (0.057) and is partially masked by body color.

Varieties

Demantoid

Demantoid is the green variety of andradite.

Melanite

Melanite is the black, opaque variety which is mostly used in mourning jewelry.

Topazolite

Topazolite is the lemon yellow variety of andradite.

Grandite

Grandite is a brownish variety of grossular-andradite and has lower values compared to the other varieties of andradite. Its name is often used to indicate the whole grossular-andradite intermediate series. Refractive index: 1.780-1.82

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16.8.3: Grossular

Grossular Garnet	
Chemical composition	$Ca_3Al_2(SiO_4)_3$alcium aluminum silicate
Crystal system	Cubic
Habit	Dodecahedra
Cleavage	None
Hardness	7.0-7.5
Optic nature	Isotropic
Refractive index	1.738-1.745
Birefringence	None
Specific gravity	3.60-3.68
Lustre	Vitreous

Diagnostics

Color

Green, yellowish-green, yellow-orange and pastel.

Inclusions

Hessonite: granular internal structure from numerous crystal inclusions, giving it an oily appearance.
Green grossular: rod-like or needle-like crystals.
Hydrogrossular: granular structure often with irregular black inclusions.

Refractometer

Hessonite and green grossular: 1.73-1.76 (singly refractive)
Hydrogrossular garnet: 1.70-1.73 (singly refractive)

Specific gravity

Grossular garnets sink in all common heavy liquids. Hydrogrossular garnet may sink slowly in methylene iodide.

Hessonite and green grossular garnet: 3.60-3.70
Hydrogrossular garnet: 3.35-3.55

Chelsea Colour Filter

Green stones may appear pinkish to red.

Varieties

Hessonite

Hessonite is the brownish-red to yellowish-orange variety.

Green grossular garnet



Figure 16.8.3.1***:*** *Faceted Mint Garnet*
Photo courtesy of Ben Pfeiffer

Green grossular garnet is the bluish-green to yellowish-green variety. Within this group, Merelani Mint garnet is a grossular variety that is found in the Merelani Hills of Tanzania. It has emerged in the last few years with a bright pastel mint green color. Due to its limited availability, it has remained mainly as a collector stone.

Hydrogrossular garnet

Hydrogrossular garnet is the green, pink, grayish-white to bluish variety of grossular.

Chrome grossular

Chrome grossular is a green variety of grossular.

Tsavorite

Tsavorite (or tsavolite) is a grossular that, like the Meralani mint, is green in colour. It is coloured by chromium and/or vanadium. The distinction between a 'regular' green grossular and tsavorite is commonly thought to be a function of saturation and tone. However, according to the Bridges' family (tsavorite was discovered by the late Campbell Bridges), the distinction is chemical. The chromophore for green grossular is iron, as opposed to chromium and/or vanadium.

Mali

Mali garnet is a yellow-green variety of grossular with a slight overlap in the grossular-andradite series.

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16.8.4: Pyrope

Pyrope Garnet	
Chemical composition	$Mg_3Al_2(SiO_4)_3$agnesium aluminum silicate
Crystal system	Cubic
Habit	Dodecahedra
Cleavage	None
Hardness	7.0-7.5
Dispersion	Medium, 0.022
Optic nature	Isotropic
Refractive index	1.730-1.760
Birefringence	None
Specific gravity	3.65-3.80
Lustre	Vitreous

Pyrope is a red, orange-red, brownish-red to pink species of the garnet group which forms isomorphous series with almandine, spessartite and grossular. Pyrope, like all other species of the garnet group, is seldom seen having its ideal chemical makeup.

Diagnostics

Spectroscope

Pyrope has a chromium spectrum that can be combined with the typical spectrum of almandine.

Inclusions

- Rounded crystals of low relief
- Rutile needles

Polariscope

Pyrope (in all its isomorphous series) may show anomalous birefringence.

Refractometer

The refraction index of pyrope is 1.714 but, because it is never found pure, its index has a lower value of 1.730 and an upper value of 1.760.

Pyrope is singly refractive (isotropic).

Specific gravity

Pure pyrope has a specific gravity of 3.58. Due to isomorphous replacement, this value is never measured. Instead, its value ranges from 3.65 to 3.80.

Pyrope sinks in all common heavy liquids.

Varieties

Rhodolite

Rhodolite is the purple variety of pyrope-almandine. The name and color come from the flower of the rhodondendron.
The jewelry trade sometimes describes every purple garnet as a rhodolite but it should be reserved only for those having an intermediate chemical composition between pyrope and almandine.

Malaia

Malaia garnet (or malaya) is the red-orange variety of pyrope-spessartite discovered in the 1970's in Kenia as a by-product of rhodolite.
The name is derived from the Swahili word for prostitute (which freely translates to "outcast" or "out of the family") [see: Swahili - English Dictionary; Rouse, 1986].

Localities

- South-Africa
- USA
- Russia

References

- Swahili - English Dictionary
- *Garnet* (1986) - John D. Rouse ISBN 0408015349

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16.8.5: Spessartite

Spessartite Garnet	
Chemical composition	$Mn_3Al_2(SiO_4)_3$anganese aluminum silicate
Crystal system	Cubic
Habit	Dodecahedra
Cleavage	None
Hardness	7
Optic nature	Isotropic
Refractive index	1.795-1.815
Birefringence	None
Specific gravity	4.12-4.20
Lustre	Vitreous



Figure 16.8.5.1***:*** *Spessartite with Smoky Quartz*
Photo courtesy of Barbra Voltaire

Spessartite image gallery

Spessartite is also named spessartine, both names are used interchangeably.

Diagnostics

Color

Orange, red, reddish-orange to yellowish-brown.

Spectroscope

Spessartite shows a typical spectrum due to manganese (idiochromatic) and some iron (from almandine).

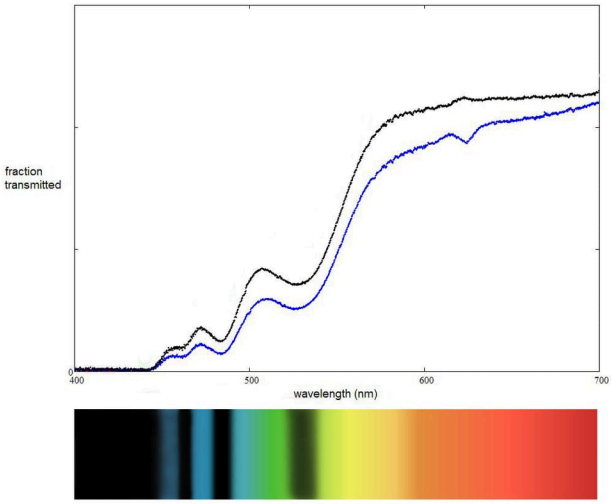


Figure 16.8.5.2***:*** *Spectra of a spessartite from the Loliondo deposit in tanzania which was discovered in 2007. The graphs represent the transmission spectrum taken with the aid of a spectrometer, the spectrum below is what you will see through a spectroscope*

Inclusions

- Feathers of liquid droplets ("shredded inclusions"), negative crystals, crystal inclusions, "suger"; multiple tiny grains (Tanzanian stones) , small colorless fibers of tirodite which cause a sleepy look (Namibian stones)

Specific gravity

4.12 - 4.20

Spessartite sinks in all common heavy liquids.

Chelsea Colour Filter

Spessartite will show red under the CCF.

Varieties

Mandarine/Kashmirine/Hollandine

Three names for the same intense orange variety of spessartite.

Malaia

Main entry: pyrope

Malaia garnet (or malaya garnet) is the red-orange variety of pyrope-spessartite.

Localities

• Sri Lanka (Ceylon)	• Burma	• Brazil
• Madagascar	• Mozambique	• Nigeria
• Namibia	• Tanzania	• USA
• China	• Pakistan	• Afghanistan
• Myanmar	• India	• Italy
• Norway	• France	• Germany
• Sweden	• Scotland	• Russia

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16.8.6: Uvarovite

Uvarovite Garnet	
Chemical composition	$Ca_3Cr_2(SiO_4)_3$alcium chromium silicate
Crystal system	Cubic
Habit	Dodecahedra
Cleavage	None
Hardness	7.5
Optic nature	Isotropic
Refractive index	1.86-1.87
Birefringence	None
Specific gravity	3.77
Lustre	Vitreous



Figure 16.8.6.1***:*** *Uvarovite*
Photo courtesy of Rick Martin

Uvarovite is hardly ever found in crystals large enough to be cut into gemstones.

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16.09: Diopside

Diopside	
Chemical composition	$CaMg(SiO_3)_2$alcium magnesium sillcate
Crystal system	Monoclinic
Habit	Prismatic, waterworn pebbles
Cleavage	Distinct
Fracture	Conchoidal
Hardness	5
Optic nature	Biaxial +
Refractive index	1.67-1.70
Birefringence	0.025
Dispersion	Low, 0.013
Specific gravity	3.3
Lustre	Vitreous
Pleochroism	Weak to moderate

Diopside is a calcium magnesium silicate that crystallizes from magmas. It is usually a fairly uninteresting component of igneous rocks, but there are a few varieties that have gemological merit. The first is a chatoyant (cat's-eye effect) variety. Occasionally, stones have been found that are chatoyant in two directions forming a four-pointed star. Ancient civilizations believed that star stones housed living spirits who were looking at you through those stars. One of the most popular varieties of diopside is chrome bearing stones which are vibrant green and transparent. These are found in Russia and East Africa. There is another variety, termed violane, that is bluish violet, used for beads and inlay work.

Diopside forms an isomorphous series with hedenbergite ($CaFe(SiO_3)_2$) and the iron that comes from hedenbergite is the prime cause of color in diopside.

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16.9.1: Chrome Diopside

Chrome Diopside	
Chemical composition	$CaMg(SiO_3)_2$alcium magnesium silicate
Crystal system	Monoclinic
Habit	Prismatic, waterworn pebbles
Cleavage	Distinct
Fracture	Conchoidal
Hardness	5
Optic nature	Biaxial +
Refractive index	1.67-1.70
Birefringence	0.025-0.030
Dispersion	Low, 0.013
Specific gravity	3.3
Lustre	Vitreous
Pleochroism	Weak to moderate



Figure 16.9.1.1***:*** *Faceted Chrome Diopside*
Photo courtesy of Rick Martin

Chrome diopside is the chromium-rich variety of diopside. Chromium gives chrome diopside a brighter green color compared to the green seen in diopside which is caused by iron.

Diagnostics

Color

Bright green to emerald green.

Inclusions

Fibrous inclusions.

Spectroscope

Fine lines in the red to deep red with narrow bands in the green-blue/blue. Not all lines may be observed.

Phenomena

Cat's-eyes

Localities

South Africa - Kimberley diamond mines
Burma
Pakistan
Siberia, Russia

References

- *Gems. Their Sources, Descriptions and Identification* 4th edition (1990) - R.Webster, B.W. Anderson
- Gemmology 3rd edition (2005) - Peter Read

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16.9.2: Tashmarine™

Tashmarine Diopside	
Chemical composition	$CaMg(SiO_3)_2$alcium magnesium silicate
Crystal system	Monoclinic
Habit	Prismatic, waterworn pebbles
Cleavage	Distinct
Fracture	Conchoidal
Hardness	5
Optic nature	Biaxial +
Refractive index	1.667-1.693
Birefringence	0.025
Dispersion	Low, 0.013
Specific gravity	3.29
Lustre	Vitreous
Pleochroism	Weak to none

Tashmarine™ is a trade name for yellowish green diopside found in, amongst other places, Tashkent, Uzbekistan.

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16.10: Feldspar

Feldspar	
Chemical composition	Potassium, sodium and calcium-aluminum silicates I. K-feldspar ($KALSi_3O_8$) II . Plagioclase feldspar (isomorphous)
Crystal system	Monoclinic - triclinic
Habit	Prismatic, often twinned
Cleavage	Good to perfect
Fracture	Conchoidal
Hardness	6
Optic nature	Biaxial ±
Refractive index	1.52 - 1.53 (K-feldspar) 1.528 - 1.588 (plagioclase)
Birefringence	0.006 - 0.007 (K-feldspar) 0.008 - 0.011 (plagioclase)
Specific gravity	2.55 - 2,58 (K-feldspar) 2.60 - 2.80 (plagioclase)
Lustre	Vitreous

Feldspar is a group of minerals that are very important in rock formation, accounting for over half of Earth's crust! There are a number of varieties that are used in jewelry. The most important are andesine, sunstone, amazonite, moonstone, and labradorite, the latter two known for their phenomenal adularescence and iridescence. Amazonite was used by the ancient Egyptians for carving images of deities, the stone considered a catalyst between the living and the gods. Moonstone was thought to drive away sleeplessness.

Feldspars are divided into two types:

- K-feldspars (potassium feldspars)
- Plagioclase feldspars (an isomorphous series between albite and anorthite)

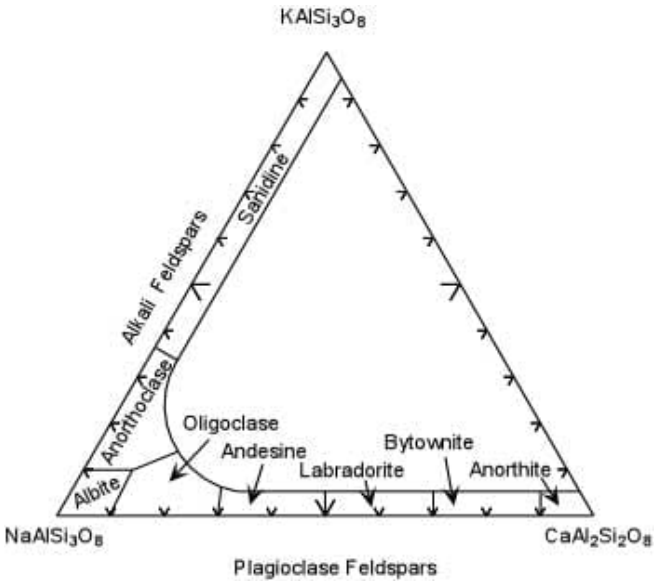


Figure 16.10.1

K-feldspar

K-feldspars grow in monoclinic crystals (except for microcline) and have a chemical composition of $KAlSi_3O_8$.

Varieties

- Orthoclase
- Orthoclase moonstone
- Microcline (amazonite)
- Sanidine

Plagioclase feldspar

Plagioclase feldspars grow in triclinic crystals. Its varieties belong to an isomorphous series between albite ($NaAlSi_3O_8$) and anorthite ($CaAl_2Si_2O_8$).

Varieties

- Albite (100-90% albite, 0-10% anorthite)
- Oligoclase (90-70% albite, 10-30% anorthite)
- Andesine (70-50% albite, 30-50% anorthite)
- Labradorite (50-30% albite, 50-70% anorthite)
- Bytownite (30-10% albite, 70-90% anorthite)
- Anorthite (10-0% albite, 90-100% anorthite)

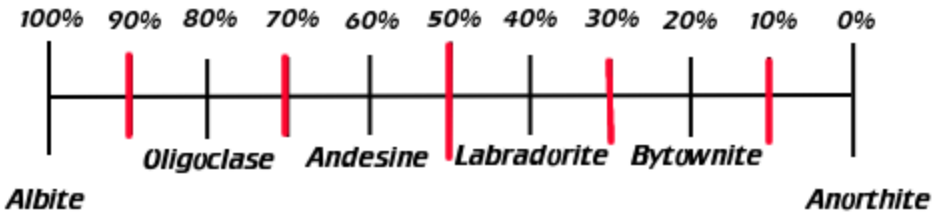


Figure 16.10.2***:*** *Timeline image indicating the percentages of the albite-anorthite series*

"Confetti" sunstone

"Confetti" sunstone is oligoclase feldspar in composition. The background color can be colorless, yellow, orange, or light green. The colorful flashes are caused by flecks or platelets of hematite. Faceted stones of good size with no fractures and plenty of hematite inclusions are always a treat to see. Tanzania is the only source we know of for this interesting gem.



Figure 16.10.3***:*** *Confetti sunstone (by Scott Davies)*



Figure 16.10.4***:*** *Confetti sunstone (by Scott Davies)*



Figure 16.10.4***:*** *Confetti sunstone (by Scott Davies)*

Short Films

FELDSPAR PHENOM
Remarkable, outstanding, exceptional—Bill Larson had an extraordinary orthoclase specimen on view at the 2009 Westward Look Show in Tucson. Dave Wilber brings us on a personalized tour of some highlights in Bill Larson's collection, including a large (we mean really big) transparent yellow orthoclase crystal from Madagascar.

Spectacular Amazonite Crystals
Joe Dorris from Pinnacle 5 Minerals, Glacier Peak Mining, talks to Wilber about the amazonite and smoky quartz specimens from Colorado.
Amazonite and Smoky quartz is a classic association. The specimens pictured here are astounding examples.

Links for Further Feldspar Information

Causes of Color in Amazonite

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16.10.01: Amazonite

Amazonite	
Chemical composition	Microcline feldspar
Crystal system	Triclinic
Habit	Massive
Hardness	6-6.5
Optic nature	Biaxial -
Refractive index	1.522-1.530
Birefringence	0.008-0.010
Dispersion	Low
Specific gravity	2.56
Lustre	Vitreous



Figure 16.10.1.1***:*** *Microcline (aka Amazonite) with albite*

Amazonite is a tradename for microcline (K-feldspar) and has a green to blue-green color.



Figure 16.10.1.2***:*** *Amazonite Cabochons*

Microcline has the same chemical composition ($KAlSi_3O_8$) as orthoclase, but it grows as triclinic crystals opposed to the

monoclinic orthoclase.

Sources

- Gems Their Sources, Descriptions and Identification *4th Edition (1990) - Robert Webster (6th ed.)*
- *Gemstones of the world, 3rd rev and exp edition* (2006) - Walter Schuman ISBN 1402740166

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16.10.02: Andesine

Andesine	
Chemical composition	$(Na,Ca)[Al(Si,Al)Si_2O_8]$
Crystal system	Triclinic
Habit	Prismatic
Cleavage	Distinct to perfect
Fracture	Conchoidal
Hardness	6.5
Optic nature	Biaxial +/-
Refractive index	1.551 - 1.560
Birefringence	0.009
Specific gravity	2.67
Lustre	Sub-vitreous

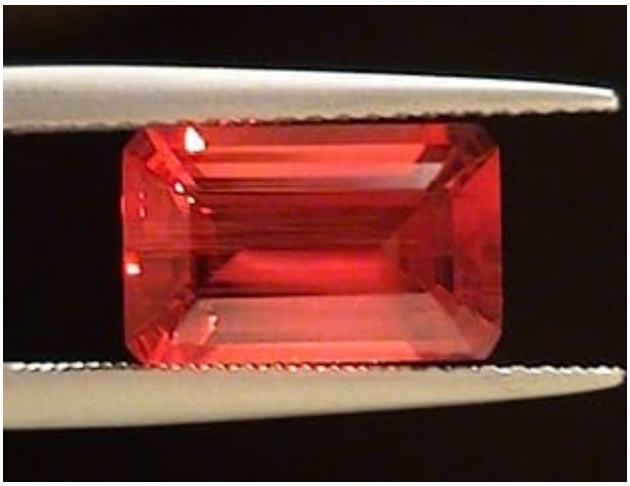


Figure 16.10.2.1***:*** *Congolese andesine*

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16.10.03: Labradorite

Labradorite	
Chemical composition	Plagioclase feldspar
Crystal system	Triclinic
Habit	Aggregates
Hardness	5-5.5
Optic nature	Biaxial +
Refractive index	1.559-1.570
Birefringence	0.008-0.011
Dispersion	Low
Specific gravity	2.70
Lustre	Vitreous



Figure 16.10.3.1***:*** *Labradorite*

Microscopic image of labradorite taken at 45x magnification (ilmenite inclusions):

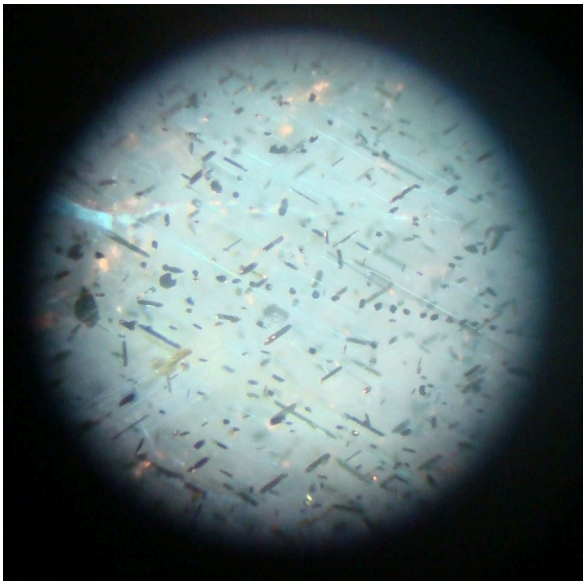


Figure 16.10.3.2

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16.10.04: Moonstone

Moonstone	
Chemical composition	K-feldspar
Crystal system	Monoclinic
Habit	Prismatic
Cleavage	Distinct to perfect
Fracture	Conchoidal
Hardness	6
Optic nature	Biaxial -
Refractive index	± 1.52
Specific gravity	2.56
Lustre	Vitreous

Moonstone image gallery

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16.10.05: Spectrolite

Spectrolite	
Chemical composition	Plagioclase feldspar
Crystal system	Triclinic
Habit	Aggregates
Hardness	5-5.5
Optic nature	Biaxial +
Refractive index	1.559-1.570
Birefringence	0.008-0.011
Dispersion	Low
Specific gravity	2.70
Lustre	Vitreous

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16.10.06: Sunstone

Sunstone	
Chemical composition	Oligoclase feldspar



Figure 16.10.6.1***:*** *An example of a rough Illusion or Confetti Sunstone from Africa*
Photo courtesy of Ben Pfeiffer

Oregon Sunstone

Sunstone image gallery

One significant source of sunstone is Oregon, USA where it is the official state gem. Small mines in Oregon produce a range of material in various colors including peach, green, and red as well as dichroic specimens.

Tanzanian Sunstone

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16.11: Spodumene

Spodumene	
Chemical composition	$LiAl(SiO_3)_2$
Crystal system	Monoclinic
Habit	Prismatic, tabular
Cleavage	Perfect, prismatic
Fracture	Uneven
Hardness	7
Optic nature	Biaxial +
Refractive index	1.66-1.68
Birefringence	0.015
Dispersion	Low, 0.017
Specific gravity	3.18
Lustre	Vitreous
Pleochroism	Strong

Figure 16.11.1***:*** *Faceted Yellow Hiddenite*
Photo courtesy of
Wild Fish Gems

Spodumene image gallery

Crystallography

Crystal system: monoclinic.
Habit: flattened and corroded prism with vertical striations, irregular capping reminiscent of Mountain range; sometimes massive. Generally long slender prismatic crystals, often etched.

Chemical composition

Lithium Aluminium Silicate ($LiAl(SiO_3)_2$).
Generally there is little Na present. Fe, Ca may replace Li; Cr may be present (Hiddenite green)

Diagnostics

Color and varieties

Hiddenite: yellow green to emerald green (due to Cr).
Kunzite: clear lilac, pink, violetish, purplish (due to Mn).
Other (Spodumene): Yellow, colourless, gray, blue (yellows due to Fe).

Magnification

Complex three phase inclusions characteristic of of spodumene; cleavages; growth tubes; needle like etch tubes; twin planes; crystals.

Luminescence

Very strong fluorescence: golden pink to orange under LWUV and weaker under SWUV.
Sometimes phosphorescent.

Pleochroism

Strong.
There is generally a strong absorption along the c-axis.

Specific gravity

Spodumene sinks in heavy liquid 2.88.

Treatments

- Irradiation (colorless to pink, other colors).
- Heat treatment (green purple or pink to lighter).

Simulants

Spodumene	
Name	**Key separations**
Euclase	Slightly lower S.G., UV fluorescence
Sillimanite	Inclusions, generally inert under UV, higher birefringence
Tourmaline	S.G. (lower heft), uniaxial character, Inclusions, R.I and D.R.
Thulite	Higher S.G., higher R.I. range and UV fluorescence
Rose Quartz	Lower S.G, R.I.
Natural Spinel	Singly refractive nature, magnification, spectrum

Hiddenite	
Name	**Key separations**
Emerald	Lower heft (floats in 2.88), uniaxial, R.I, D.R., magnification features
Chrysoberyl	Higher S.G. (heft), spectrum, R.I.
Diopside	Higher S.G., R.I., spectrum and stronger doubling of Back facet edges or inclusions

Kunzite	
Name	**Key separations**
Amethyst	Lower S.G. (floats 2.88), UV reaction unlike spodumene, bull's-eye optic figure, R.I.
Morganite	Lower S.G. (floats 2.88), uniaxial, R.I., magnification features

Topaz	Higher heft, low birefringence and UV reaction unlike spodumene
Pink sapphire	Higher heft, R.I higher and lower birefringence

Occurrence

Geological occurrence: Spodumene occurs in granite pegmatites, sometimes with very great sizes.

Geographical occurrence: Mainly North and South America; Madagascar; Burma; Brazil. USA: N.Carolina (yellowish green)-hiddenite; Connecticut (lilac); CA (Kunzite); Coahulia Mountains (yellow, yellowish green, bluish pink) Madagascar: Kunzite, green, yellowish - Anjanabonoina. Brazil: Paler hiddenite, white spodumene, cat's eye, yellow to pale green, bluish pink Kunzite, yellow and green Burma: Spodumene from upper Mogok stone tract (blue) Afghanistan: Kunzite, yellow, blue and green.

References

- Gems Their Sources, Descriptions and Identification *4th Edition (1990) - Robert Webster (6th ed.)*
- *Colour Encyclopedia* - J.E. Arem ISBN 0412989115

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16.11.01: Hiddenite

Hiddenite	
Chemical composition	$LiAl(SiO_3)_2$ithium aluminum silicate
Crystal system	Monoclinic
Habit	Prismatic
Cleavage	Perfect, prismatic
Fracture	Uneven
Hardness	7
Optic nature	Biaxial +
Refractive index	1.66-1.68
Birefringence	0.015
Dispersion	Low, 0.017
Specific gravity	3.18
Lustre	Vitreous
Pleochroism	Strong

Hiddenite is the yellow to green variety of spodumene.

It was originally discovered in Hiddenite, North Carolina.

On The First Discovery And Early Mining of Hiddenite in North Carolina

The first specimens of the hiddenite variety of spodumene were recovered about 1879 in the tiny settlement of White Plains, west of Stony Point, Alexander County, North Carolina. According to contemporary accounts, a young man named Lackey brought them to the attention of J.A.D. Stephenson, a local merchant who was also an ardent collector of mineral and archaeological specimens (Anonymous, 1885). Stephenson had posted a reward for any and all interesting specimens brought in by local farmers, among which were included “green bolts” (the emeralds for which the region would later become renowned) and yellowish green transparent crystals which were found loose in the soil with the emeralds. Initially, the yellowish to greenish-yellow hiddenites were thought to be gemmy diopside, and Stephenson sent the specimens to Norman Spang of Pittsburg, PA, a prominent US mineral collector of the era. Soon afterward, Stephenson brought the discovery to the attention of William Earl Hidden, who had been commissioned by Thomas Edison to search for any sources of platinum in North Carolina (an effort that was, in and of itself, stunningly unsuccessful). Hidden sent samples of the odd green material to John Lawrence Smith, a prominent chemist and mineralogist of Louisville, Kentucky. Smith correctly identified the specimens as being Spodumene and named them “Hiddenite” in honor of Hidden. Smith's analysis of hiddenite did not note the presence of chromium; two years later, Friedrich A. Genth, Pennsylvania's State Mineralogist, published an analysis of hiddenite which detected chromium as 0.18% chromium oxide (Genth, 1883). During the hey-day of hiddenite mining in the 1880s and 1890s, it was also known as “lithia emerald”.

Hidden recognized the value of the emeralds and the potential of the new gemmy green spodumene. He acquired a tract of poor quality land from J Washington Warren, which was either the site of the initial discovery or near to it, for $1500 (the sale price was approximately three times the value of the land). The Emerald and Hiddenite Mining Company was organized and excavations on the site quickly recovered loose hiddenites and emeralds in the red, gravelly clay. At a depth of about 26 feet they struck bedrock and soon were uncovering hiddenites from solid rock. Oddly, period newspaper accounts and statements by Kunz (1892) indicate that mining on the site was never undertaken as a full-time operation, but was only prosecuted a few weeks or months during the summer. Writing in 1892, Kunz described the hiddenite being recovered as “always transparent, ranges from colorless (rare) to a light yellow, into a yellowish green, then into a deep yellow emerald green. Sometimes an entire crystal has a uniform green color, but generally one end is yellow and the other green.” He added “The yellow color exhibited by the mineral in even the darkest

green gems will prevent it from competing with the emerald, since it is this very quality that has kept down the prices of the Siberian demantoids or Uralian emeralds as the green garnets are variously termed. Dr. J Lawrence Smith says that the crystals, when cut and polished, resemble the emerald in luster, though the color is not so intense as in the finer variety of the latter gem. Prof. Edward S Dana says that, owing to its dichroism, it has a peculiar brilliancy which is wanting in the true emerald." Kunz noted that the finest crystal recovered prior to 1892 measured 68 mm tall, and could have cut a gem of 5.5ct estimated weight. The size of most cut gems were small, with a 2ct hiddenite in the Augustus C. Hamlin collection being considered among the finest of the large stones. Between 1880 and 1888 approximately $7,500 worth of Hiddenite was produced, with values ranging from $40 to $100 a carat (1892 US dollars).

Magnification

Hiddenite is a Type I stone in the GIA clarity grading system meaning it is usually eye-clean.
Typical inclusions are:

- liquid inclusions, 2-phase and 3-phase

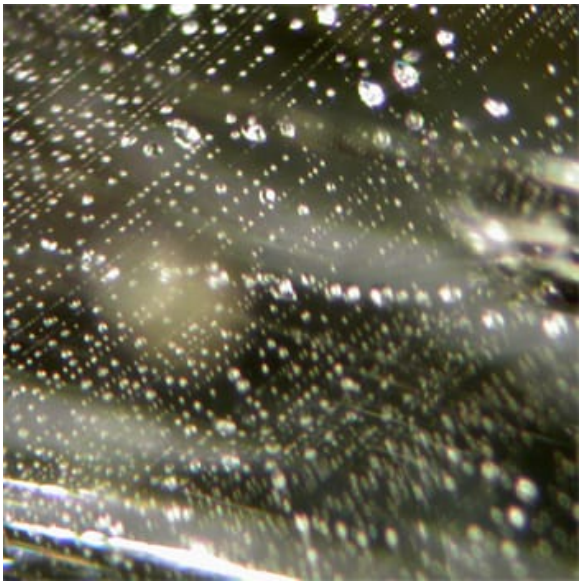


Figure 16.11.1.1***:*** *Planes of liquid 2 and 3-phase inclusions*
30X Magnification
by Barbra Voltaire

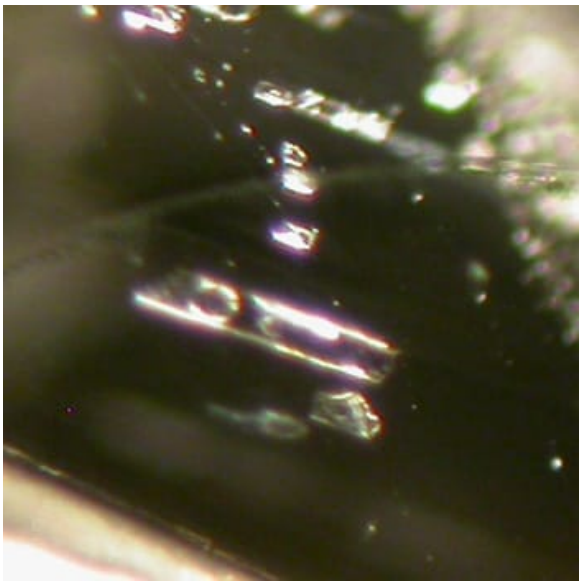


Figure 16.11.1.2***:*** *Close-up of 3-phase inclusion*
80X magnification
by Barbra Voltaire

Sources

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- Smith, J. L. (1881) American Journal of Science Vol. 21 ser 3 pp128-30 (1881) *Hiddenite, an emerald-green variety of spodumene*

- Gemmology 3rd edition (2005) - Peter Read

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16.11.02: Kunzite

Kunzite	
Chemical composition	$LiAl(SiO_3)_2$ithium aluminum silicate
Crystal system	Monoclinic
Habit	Prismatic
Cleavage	Perfect, prismatic
Fracture	Uneven
Hardness	7
Optic nature	Biaxial +
Refractive index	1.66-1.68
Birefringence	0.015
Dispersion	Low, 0.017
Specific gravity	3.18
Lustre	Vitreous
Pleochroism	Strong



Figure 16.11.2.1***:*** *Emerald-cut Kunzite (47.5 carats)*
Photo courtesy of Barbra Voltaire

Kunzite is the pink, lilac or violet variety of the mineral spodumene. It is a lithium aluminum silicate named after the famous gemologist George F. Kunz, who was the first to identify it. Kunzite was first found in Connecticut. But the first commercially significant deposit was discovered in 1902 in the Pala region of California, where morganite beryl was also first discovered. Kunzite is often found in association with morganite and pink tourmaline, the other popular pink gemstones. Today, most kunzite is mined in Brazil, Afghanistan, and Madagascar. The largest faceted kunzite is an 880ct specimen on display at the Smithsonian Institution in Washington D.C. Although kunzite for jewelry use is several levels of magnitude smaller, kunzite shows the best color in larger sizes. Stones should be at least ten carats to be really "in the pink".
Unfortunately, most kunzite fades in sunlight so it should ideally be worn at night. It is a highly dichroic gem, meaning that it appears two different colors, depending upon which direction you view it. In one direction, it will appear pink, violet or lilac, and in

the other direction, it will appear colorless. Therefore, it is important to cut it so that the direction of most intense color is visible in a face-up direction.

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16.12: Chrysoberyl

Chrysoberyl	
Chemical composition	$BeAl_2O_4$
Crystal system	Orthorombic
Habit	Pseudo-hexagonal twins
Cleavage	Weak to moderate
Fracture	Conchoidal to uneven
Hardness	8.5
Optic nature	Biaxial +
Refractive index	1.74-1.75
Birefringence	0.009
Dispersion	Low, 0.014
Specific gravity	3.72
Lustre	Bright vitreous
Pleochroism	Moderate to strong

Figure 16.12.1***:*** *Chrysoberyl*
Photo courtesy of John Huff, gemcollections.com

Chrysoberyl image gallery

Chrysoberyl is a beryllium aluminum oxide, not at all related to the mineral beryl, which is a silicate. Chrysoberyl can occur in various shades of green, yellow, brown, red, and occasionally blue. The most valuable varieties of chrysoberyl are alexandrite, and cat's eye. Cat's eye was long admired in the orient for its chatoyant character, but it wasn't popular in the West until the late 1800s. The third and most common variety of chrysoberyl is a transparent greenish yellow stone. It was very popular in Victorian and Edwardian jewelry. Cat's eye is believed to protect one from evil spirits or the evil eye. According to the Hindus, the stone would preserve your health and guard against poverty. In Asia, it was thought that if you pressed a cat's eye between your own eyes it would enhance your foresight.

Phenomena

Cat's-eyes

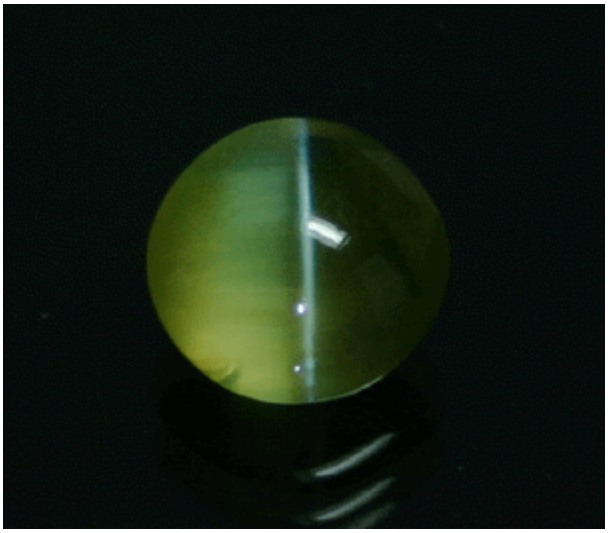


Figure 16.12.2***:*** *Cat's Eye Chrysoberyl*
Photo courtesy of The Gem Trader

G&G Articles on Chrysoberyl 1934-1980

The GIA has published all the G&G's from 1934 until 1980 online. The organization of the list by subject was done by Joseph Gill.

- Jan. 1934, **Chrysoberyl**, p. 9, 2pp.
- Winter 1937, **A grayish-green star chrysoberyl**, p. 130, 1p.
- Fall 1945, **A 115 ct. star chrysoberyl (non-gem quality)**, by Anderson, p. 252, 2pp.
- Spring 1949, **The Origin of Alexandrite Color Change**, p. 143, 3pp.
- Spring 1949, **Chrysoberyl**, p. 147, 1p.
- Fall 1953, **Inclusions in Yellow Chrysoberyl**, by Webster, p. 343, 4pp.
- Spring 1954, **Separating yellow chrysoberyl and yellow corundum**, p. 32, 1p.
- Spring 1959, **A 45 ct., a 12 ct., and a 50 ct. alexandrite**, p. 264, 1p.
- Summer 1960, **A 4-rayed star brown chrysoberyl**, p. 62, 1p.
- Winter 1963, **A cat's-eye alexandrite**, p. 104, 2pp.
- Fall 1964, **Synthetic alexandrite made**, p. 216, 1p.
- Fall 1967, **Cat's-Eye Doublet**, p. 215, 2pp.
- Summer 1970, **High-Property Cat's-Eye** (R.I. 1.76–1.77), and absorption spectrum, p. 184, 2pp.
- Winter 1972, **Synthetic alexandrite, introduced to the market by Creative Crystals, Inc.**, Danville, Calif., p. 102, 3pp.
- Winter 1972, **Chrysoberyl cat's-eye, proved to be natural**, p. 113, 1p.
- Winter 1972, **Fine cat's-eye glass with milk and honey effect**, p. 108,
- Spring 1973, **Fine cat's-eye glass and optic fibers with milk and honey effect**, p. 136, 3pp.
- Winter 1974, **A new synthetic alexandrite by the Czochralski Method**, p. 367, 3pp.
- Summer 1976, **A very rare 4-ray star cat's-eye chrysoberyl**, p. 170, 1p.
- Fall 1976, **Alexandrite from Lake Manyara, Tanzania**, by Gübelin, p. 203, 11 pp., with bibliography
- Fall 1976, **African alexandrites?**, p. 211, 3pp.
- Spring 1979, **Natural & Synthetic Alexandrites**, p. 148, 1p.
- Spring 1980, **Fiber optic cat's-eye imitation**, p. 278, 1p.
- Summer 1980, **A Giant Chrysoberyl Crystal**, p. 320, 2pp.

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16.12.01: Alexandrite

Alexandrite	
Chemical composition	$Al_2(BeO_4)$Beryllium aluminum oxide
Crystal system	Orthorhombic
Habit	Tabular, pseudo-hexagonal
Cleavage	Imperfect prismatic
Fracture	Weak, conchoidal
Hardness	8.5
Optic nature	Biaxial +
Refractive index	1.744 - 1.755
Birefringence	0.009
Dispersion	Low, 0.014
Specific gravity	3.70 - 3.72
Lustre	Bright vitreous
Pleochroism	Strong



Figure 16.12.1.1***:*** *Adularescent Alexandrite 26.74 carats*
Tunduru, Ruvuma, Ruvuma Region, Tanzania



Figure 16.12.1.2***:*** *Alexandrite from Hematia, Minas Gerais, Brazil*
Viewed in daylight (greenish) and with LWUV (reddish)



Figure 16.12.1.3***:*** *Alexandrite crystals photographed in candle light and daylight*
Yekaterinburg, Russia

Alexandrite is a phenomenal variety of the mineral chrysoberyl. Because of the trace amounts of the chromophores vanadium and chromium, alexandrite appears different colors depending on whether it is viewed in natural or incandescent light. In daylight, the stone appears to be green; in artificial light it appears to be raspberry red. It was originally discovered in the Ural Mountains in 1830 on the birthday of Czar Alexander of Russia. Another extraordinary coincidence was that the national colors of Russia were red and green. Today, alexandrite is found in Russia, Brazil, India and to a lesser extent in Africa. Alexandrite has long been associated with great luck and prosperity.

Inclusion Images



Figure 16.12.1.4***:*** *Liquid veil and twinning resembling a venetian blind effect*
Courtesy of Barbra Voltaire

Additional Phenomena

Alexandrite image gallery

- Cat's Eye

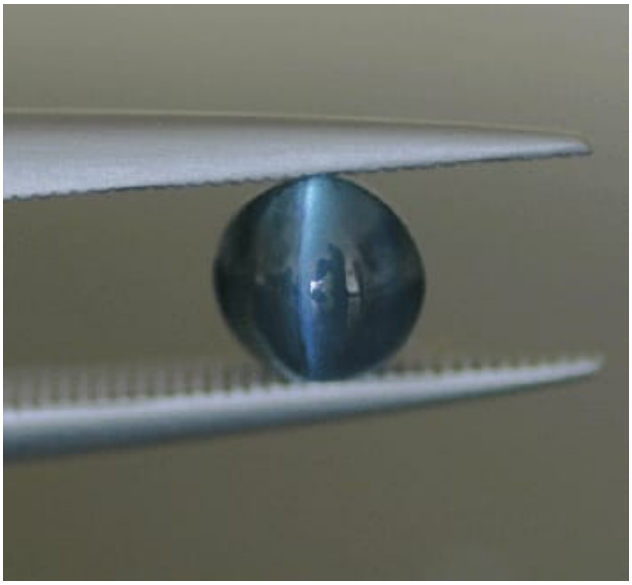


Figure 16.12.1.5***:*** *Cat's eye Alexandrite under daylight*
Photo courtesy of The Gem Trader

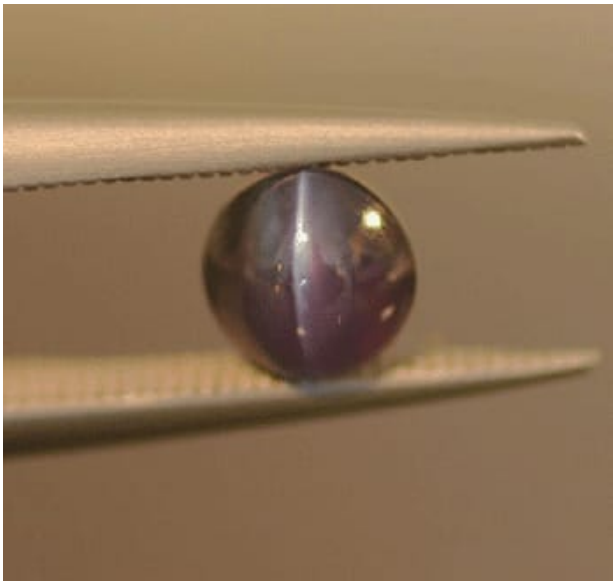


Figure 16.12.1.6***:*** *Cat's eye Alexandrite under incandescent light; Photo courtesy of The Gem Trader*

G&G Articles on Alexandrite 1934-1980

The GIA has published all the G&G's from 1934 until 1980 online. The organization of the list by subject was done by Joseph Gill.

- Spring 1949, **The Origin of Alexandrite Color Change**, p. 143, 3pp.
- Spring 1959, **A 45 ct., a 12 ct., and a 50 ct. alexandrite**, p. 264, 1p.
- Winter 1963, **A cat's-eye alexandrite**, p. 104, 2pp.
- Fall 1964, **Synthetic alexandrite made**, p. 216, 1p.
- Winter 1974, **A new synthetic alexandrite by the Czochralski Method**, p. 367, 3pp.
- Fall 1976, **Alexandrite from Lake Manyara, Tanzania**, by Gübelin, p. 203, 11 pp., with bibliography
- Fall 1976, **African alexandrites?**, p. 211, 3pp.
- Spring 1979, **Natural & Synthetic Alexandrites**, p. 148, 1p.

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16.13: Spinel

Spinel	
Chemical composition	$Mg(Al_2O_4)$ Magnesium aluminum oxide
Crystal system	Cubic
Habit	Octahedral, contact twins
Cleavage	Imperfect
Fracture	Conchoidal, uneven
Hardness	8
Optic nature	Isotropic
Refractive index	1.712 - 1.736
Birefringence	None
Dispersion	0.026
Specific gravity	3.58 - 3.61
Lustre	Vitreous
Pleochroism	None

Figure 16.13.1***:*** *Spinel from Kuh-i-Lal, Tajikistan*

Spinel image gallery

Spinel is a mineral group. For many centuries, most gem spinels were misidentified as sapphire or ruby because they have similar properties and occur in the same geological deposits. The historically significant 5.08 centimeter "Black Prince Ruby" in the center of the British Imperial Crown was only recently identified as a spinel. This stone is irregular in shape and has a somewhat squareish outline. Additionally, it was not faceted, merely polished. Spinels also occur in a vast array of colors. They are slightly softer than sapphires but still very durable.
The earliest known use of spinels was as ornaments found in Buddhist tombs in Afghanistan. Blue spinels have been found in England, dating back to the Roman occupation (51 BC to 400 AD).

Chemical composition

Common spinel belongs to the spinel series in the spinel group.
The general formula for the spinel group is $A^{2+}B^{3+}{}_2O_4$. The three series of the spinel group are defined by the B^{3+} cation.
The spinel group is made up of 3 isomorphous series.

The isomorphous series:

- Spinel series (aluminum)
  - Spinel - $MgAl_2O_4$ (n = 1.719, sg ~ 3.60)
  - Hercynite - $FeAl_2O_4$
  - Gahnite - $ZnAl_2O_4$ (n = 1.805, sg = 4.62)
  - Galaxite - $MnAl_2O_4$

- Magnetite series (ferric iron)
  - Magnetite - $FeFe_2O_4$

    - Magnesioferrite - $MgFe_2O_4$
    - Ulvöspinel - $FeFeTiO_4$
    - Franklinite - $ZnFe_2O_4$
    - Jacobsite - $MnFe_2O_4$
    - Trevorite - $NiFe_2O_4$

- Chromite series (chrome)
    - Chromite - $FeCr_2O_4$
    - Magnesiochromite - $MgCr_2O_4$

Most of the above series members are rare in nature with the exception of the members of the spinel series, magnetite and chromite. To gemologists common spinel and gahnite are of most interest.

When gemologist refer to "spinel", we usually imply common spinel, that is the spinel that belongs to the spinel series of the spinel group.

Diagnostics

Spinel can be confused with many stones by appearance alone, yet optical properties usually rule out most of them.
As spinel belongs to an isomorphous series, the optical and physical properties may vary.

Color

Spinel: colorless, green, blue, red, black.
Gahnite: blue-green, yellow, brown.

Varieties:

- Pleonaste (also named ceylonite) - $(Mg,Fe)Al_2O_4$ - dark green to blue-green; black
- Gahnospinel - $(Mg,Zn)Al_2O_4$ - pale to dark blue, black.

Spinel is allochromatic and variety colors are produced by transition metals:

- Cr^{3+} - red, pink
- Fe^{2+} - blue, violet
- Fe^{2+} + Co^{2+} - dark blue
- Fe^{3+} - green

Diaphaneity

Transparent to opaque.

Refractometer

Spinel is isotropic and the refractive index of common spinel is generally around 1.712 to 1.720. Red spinel can have a refractive index up to 1.74.
The only other isotropic gemstone that falls within this range is grossular garnet, but it will usually be higher and the color is also different.
Other members of the spinel series, such as gahnite will have higher refractive indices.

All other gemstones can easily be separated from spinel by their optic nature.

Synthetic spinel has a usual refractive index of 1.727.
Gahnospinels have a refractive index between 1.725 and 1.753, while pleonaste (ceylonite) has an R.I. range of 1.77 to 1.80.
Black spinel-hercynite (pleonaste) stones from Thailand may have an RI up to 1.789 with an average SG of 3.86 (Seriwat, 2008)

Specific gravity

As with the refractive indices, the specific gravity of spinel can vary due to isomorphous replacement.
The values for most gem grade material lies between 3.58 and 3.61. Pleonaste has a S.G. between 3.63 and 3.90.
Gahnospinels may have a specific gravity up to 4.06.

Polariscope

Common spinel is isotropic and will remain dark under crossed polars.
Verneuil type synthetic spinel will, with the exception of the red variety, show strong anomalous birefringence due to excess Al_2O_3 (see synthetics). This anomalous extinction (as it is currently named) is known as "tabby" extinction, resembling the color distribution of a tabby cat's fur pattern, or/and as an Andreas cross caused by pseudo-birefringence. The cause of this tabby extinction is the excess alumina when compared with the natural.

Natural and flux-melt synthetic spinel may show weak anomalous extinction. When examined under magnification, this can often be seen to relate to be crystallographically related, where the light areas form parallel zones.

Spectra

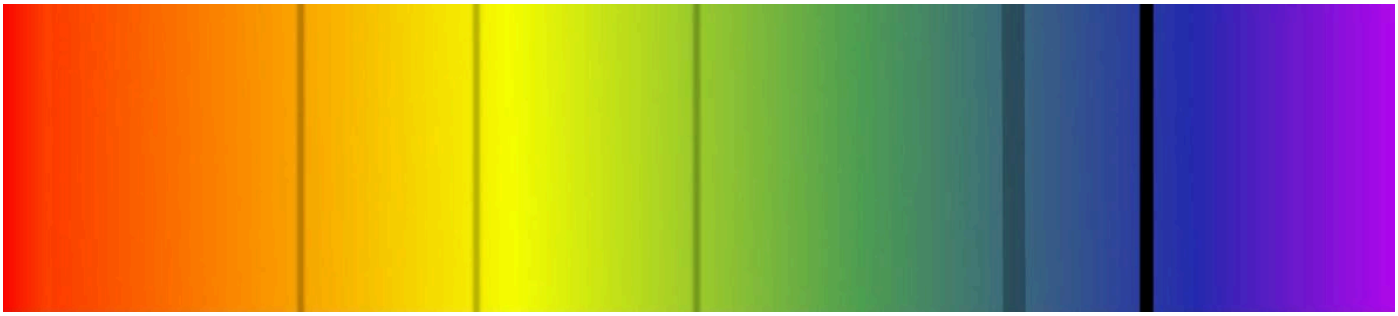


Figure 16.13.2***:*** *Spectrum of a natural blue spinel, colored by iron and minor traces of cobalt.*

Treatments

Like any gem, spinels that contain surface-reaching fissures may have those fissures filled with a colorless or colored oil/resin/glass to reduce their visibility. Filled spinels are becoming more and more common as the price of this gem increases.

Various reports have indicated that gem treaters are experimenting with heating spinel to improve its appearance. As of 2012, only slight changes have been reported. Most of the change after treatment appears to be due to a slight improvement in the clarity of certain specimens. Heated spinels can be identified by reference to a broadening of the Raman line width at 405 cm^{-1} and by the R-line width in fluorescence.

Phenomena

- Asterism (4 and 6-pointed stars)
- Color change (rare)
- Cat's eye (rare)

Occurrence

The major sources for gem spinel are Myanmar, Sri Lanka, Tanzania, Madagascar, Vietnam & Tajikistan. It has also been found in Thailand (only black), Pakistan, Kenya, South Africa & Brazil.

Synthetics

Spinel is synthesized by the Verneuil (flame-fusion), the flux-melt and Czochralski (pulling) methods.

Flame fusion

Flame fusion synthetic spinels have been produced since 1908 (by accident while creating synthetic corundum) but were not commercially available until 1930.

In natural spinel, the ratio of MgO to Al_2O_3 is 1:1. With the Verneuil synthetic, it was found that if boules were grown in a 1:1 ratio, they would easily fracture and no reasonably sized gemstones could be cut. By changing that ratio to 2:1 (i.e., by doubling the amount of alumina), large, clean boules could be grown.

Because the chemical formula of the Verneuil synthetic no longer matches the natural stone, it is not a true synthetic, but is generally accepted as such. Sometimes these synthetics are termed "beta corundum," due to the excess of alumina.

The result of this additional alumina in the Verneuil synthetic is an elevated refractive index (1.727), specific gravity (3.64) and "tabby" extinction between crossed polars.

When red spinel was grown at a 2:1 ratio, the boules cracked, and so were not commercially produced. A small amount of red spinel has been grown by the Verneuil process in a 1:1 ratio. Faceted stones are generally less than two carats, as the boules were heavily fractured. The few red synthetics that are created through the Verneuil process will generally show curved growth lines, even more obvious than their synthetic corundum cousins.

Larger synthetic red spinels have been grown with the flux-melt method.

A synthetic spinel imitation of moonstone was also once manufactured. It was made in a 1:3 ratio, with the excess alumina unmixing to produce a schiller-like effect. These stones sometimes feature a mirror-like coating on the flat cabochon base to enhance the effect. The RI is 1.728 with an SG of 3.64.

For a brief time, a lapis lazuli imitation was made by sintering a synthetic spinel powder together with cobalt. In a strange twist, tiny bits of genuine gold were sometimes added to simulate the "fool's gold" (pyrite) of natural lapis lazuli. The RI is 1.725, SG is 3.52, with a strong cobalt absorption spectrum.

A star spinel has also been synthesized, featuring a 4-rayed star.

Properties of flame fusion synthetic spinel

Color	Coloring agent(s)	RI	SG	Other diagnostic tests
Colorless	none	1.728–1.740	3.65–3.80	LW UV: green; SW UV: white/blue
Red	Cr^{3+}	1.722–1.725*	3.58–3.60	curved striae; spectrum; fluorescence
Pink	Cu	1.727–1.740	3.65–3.80	
Yellow	Mn	do.	do.	LW/SW UV: green
Emerald green	Mn + Co^{3+}	do.	do.	
Tourmaline green	Cr^{3+}	do.	do.	spectrum
Beryl green	Cr^{3+} + Mn	do.	do.	spectrum
Zircon blue	Co^{3+} + Cr^{3+} + Ti	do.	do.	spectrum
Sapphire blue	Co^{3+}	do.	do.	spectrum; fluorescence; CCF
Amethyst violet	Co^{3+} + Mn	do.	do.	
Alexandrite color change	Cr^{3+} + V	do.	do.	spectrum

Lapis lazuli imitation	Co^{3+}	1.725	3.52	spectrum; CCF
* Henn, 1995 mentions a low value of 1.720.				

Flux-melt

First commercial production of flux-melt synthetic spinel started around 1980, although successful experiments date back to 1848 (by the French chemist Ebelmen). As of 1989 larger volumes of this synthetic appeared on the market, produced in Novosibirsk, Russia.

Apart from red, blue synthetics have also been produced by the flux-melt process. These are true synthetics, manufactured with a 1:1 ratio of magnesia to alumina, just like natural spinel. As a result, they will show identical RI's, SG's and polariscope reactions.

Properties of flux-melt synthetic spinel				
Color	**Coloring agent(s)**	**RI**	**SG**	**Other diagnostic tests**
Red	Cr^{3+}	1.716-1.719	3.58-3.62	LW/SWUV: distinct red-orange/red residual flux inclusions
Blue	Co^{2+} + Fe^{2+}	1.719	3.58	Spectrum; SWUV: inert; LWUV: Weak red residual flux inclusions

Tabby extinction is also seen in these synthetics. Careful observation of inclusions is the main means of separation for red stones. Blue flux-melt synthetics can also be distinguished by the spectrum.

Czochralski (pulling)

A recent development (2007) is the production of red to pink synthetic spinels by the Czochralski pulling method.

Inclusion images: Click on Image for Full Size

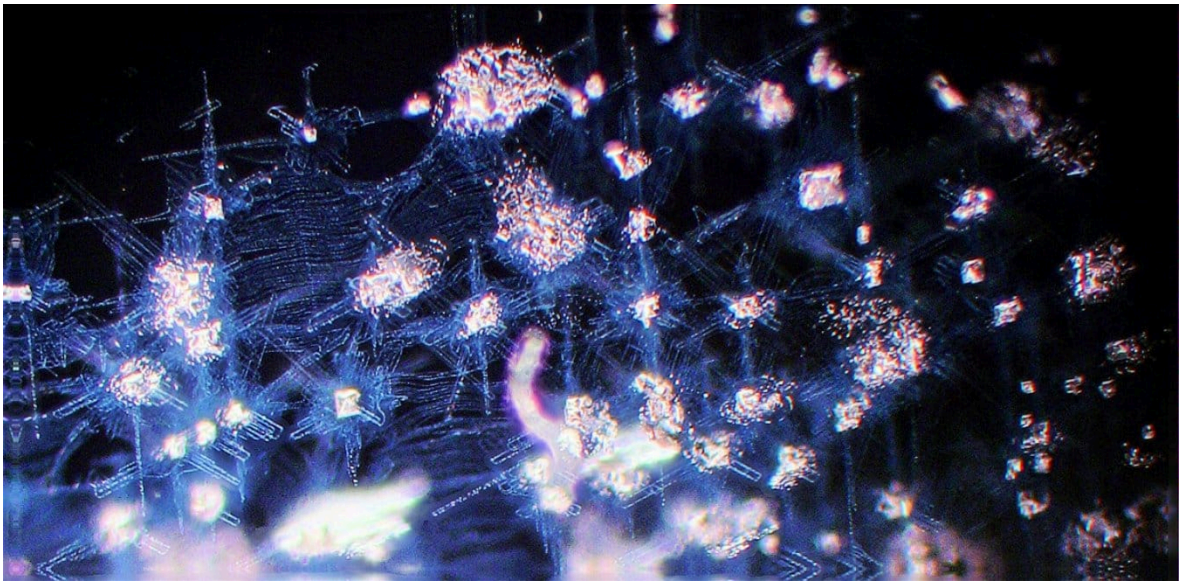


Figure 16.13.3***:*** *Apatite inclusions and their star-like outgrowths along the 60-degree hexagonal plane - looking much like stellate dislocation systems, in a cobalt blue spinel.*
Photo courtesy of John Huff, gemcollections.com

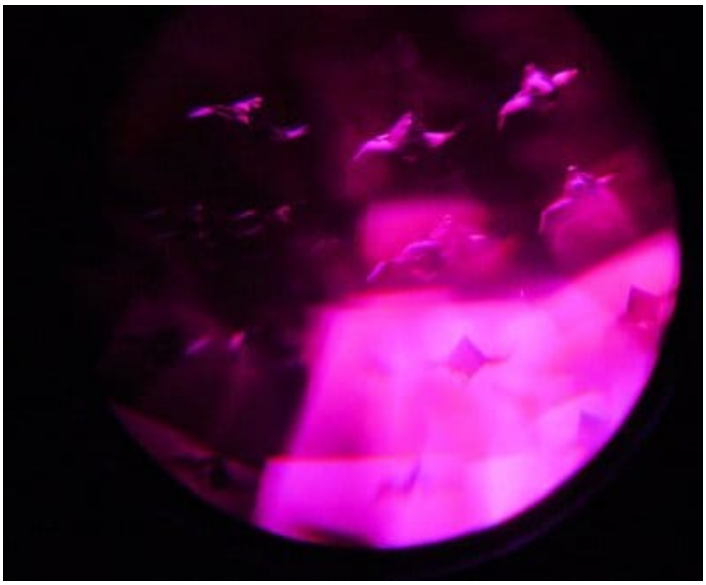


Figure 16.13.4***:*** *Octahedral spinel inclusions with "Saturn-ring" stress fractures in a Burma red spinel. Photo courtesy of John Huff, gemcollections.com*

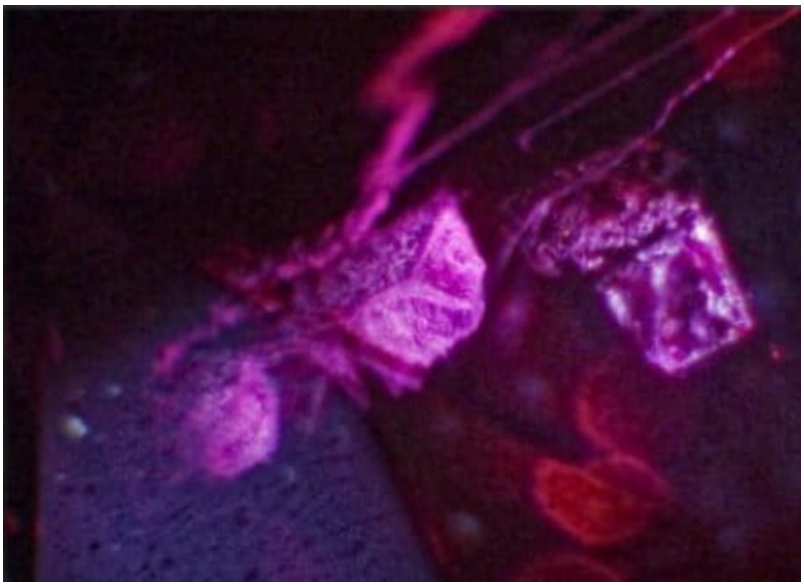


Figure 16.13.5***:*** *Octahedral inclusions in a Burma red spinel. Photo courtesy of John Huff, gemcollections.com*

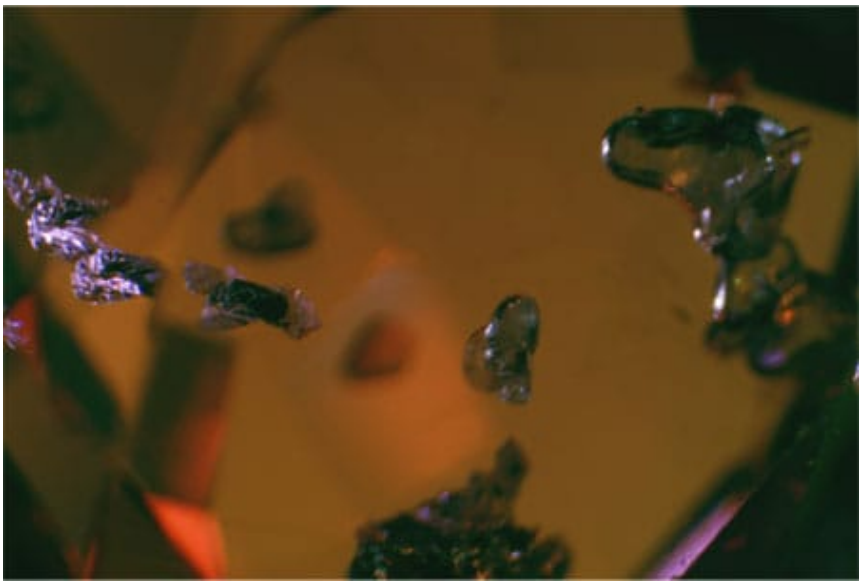


Figure 16.13.6***:*** *Euhedral inclusions in spinel.*
Photo courtesy of Conny Forsberg

Spinel inclusions gallery

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16.14: Tourmaline

Tourmaline	
Chemical composition	Complex borosilicate
Crystal system	Trigonal
Habit	Trigonal prisms with convex faces
Fracture	Conchoidal
Hardness	7.5
Optic nature	Uniaxial -
Refractive index	1.62 - 1.64
Birefringence	0.014-0.021 (up to 0.039)
Dispersion	Low, 0.018
Specific gravity	3.06 (3.01-3.11)
Lustre	Vitreous
Pleochroism	Weak to strong



Figure 16.14.1***:*** *Bi-color tourmaline*
Photo courtesy of Lembeck Gems

Tourmaline image gallery

Tourmaline is an extremely complex borosilicate that occurs in more than 100 colors. It is hard and durable and very well suited for jewelry. It is a pyroelectric mineral, meaning that when warmed, it attracts dust and other lightweight particles. The Dutch later noticed this property and called the crystals "aschentreckers," and used them to pull ashes out of tobacco pipes. It wasn't introduced into Europe until the early 1700's, when it was imported from the Ceylon by the Dutch. Shortly thereafter it was declared a stone of the Muses, inspiring and enriching the creative processes. It was a talisman for artists, actors and writers. Today, it is mined extensively in South America, East Africa, and in San Diego County, California.

Tourmaline group

Tourmaline is a large group consisting of complex borosilicates.

Species

Only 5 species of tourmaline are of real importance to gemologists.

- Elbaite
  - Elbaite is a, lithium rich, species of the tourmaline group and the name elbaite is named after the island of Elba,Italy.

    Most tourmaline gemstone varieties on the market belong to this species.
- Liddicoatite
- Dravite





Figure 16.14.2***:*** *Faceted Dravite Tourmaline*
Photo courtesy of The Gem Trader

- Chromdravite

- Schorl
  - Schorl is the, iron rich, black variety of the tourmaline group and is used in mourning jewelry. Its name comes from the old mining expression for 'false one'.

From the above 5, elbaite is the most important one. Discrimination between elbaite and liddicoatite is usually not attempted.

Varieties

There are many, mainly color, varieties of these species.

Color varieties (names apply to all species).

- Achroite - colorless tourmaline
- Rubellite - red tourmaline (color due to iron and manganese)
- Indicolite - blue tourmaline (color due to iron)
- Verdelite - green tourmaline (color due to iron and titanium)
- Siberite - reddish-violet tourmaline
- Watermelon - a pink core with green edges

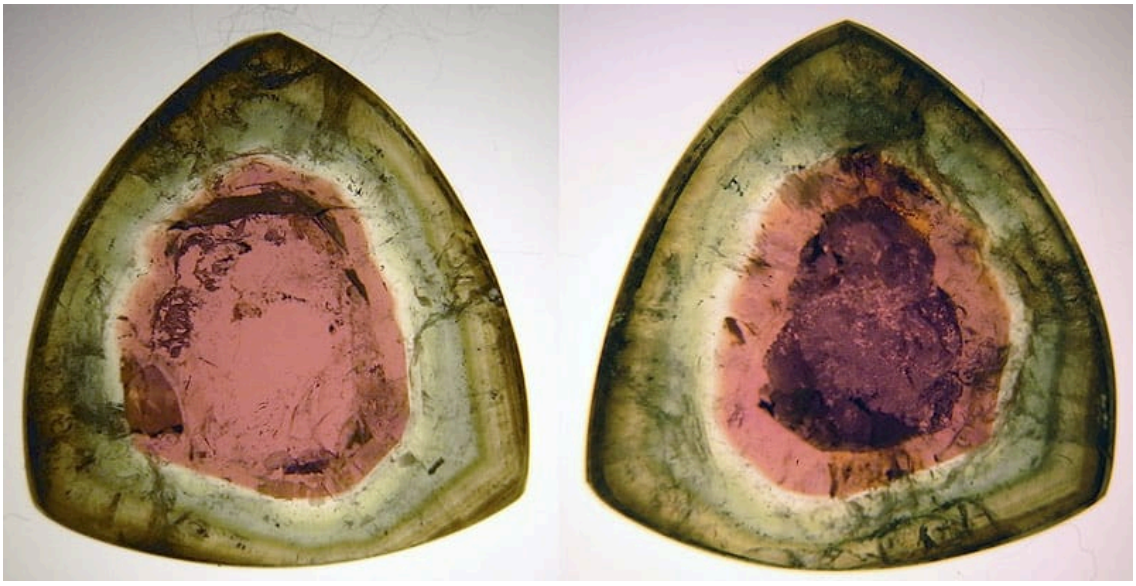


Figure 16.14.3***:*** *Watermelon Tourmaline Slices*
Photo courtesy of Olivier Louy, M.Sc, A.G. (HH)

- Bi-color - two colored tourmaline
- Tri-Color - three colored tourmaline

Other varieties.

- Paraiba - neon colored elbaite tourmaline (color due to copper and manganese)

Diagnostics

Color

Tourmaline occurs in almost any color. Bi-colored specimens and "watermelons" are common.

Refractive index

The refractive index of tourmaline lies between 1.610 and 1.698 (usually between 1.62 and 1.64) with a birefringence up to 0.039 (usually 0.019).
n_ω = 1.631-1.698, n_ε = 1.610-1.675, optic sign is negative.
The indices of refraction increase with higher iron content.

Probably due to thermal shock (and/or heat treatment), some stones may show 4 (or even 8) different values per reading. This effect is named the "Kerez effect". Careful recutting of the stone will reveal that it is an outer-edge phenomenon [Dietrich, 1985].

Polariscope

Some dark colored tourmalines have a so-called "closed axis" due to strong selective absorption in the direction of the optic axis and an interference figure may be hard (if not impossible) to find in that case.
Lighter colored stones may be cut with the optic axis perpendicular to the table and good interference figures can be found there.

Some tourmalines show pseudo-biaxial (due to internal stress) interference figures on lateral rotation with a 2V up to 25° [Nesse, 2004; Dietrich, 1985].

Magnification

Tourmalines can be of type I to type III clarity grades.
Typical inclusions are:

- Trichites (small thread-like twists)
- Flattened liquid channels running parallel to the optic axis.
- Liquid Veils
- 2 and 3-Phase Inclusions
- Hollow tubes

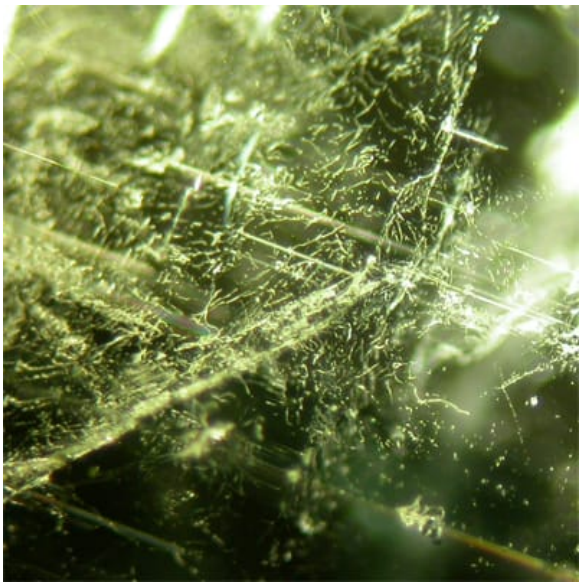


Figure 16.14.4***:*** *Tourmaline with liquid veils, hollow tubes and phase inclusions*
40X Magnification
by Barbra Voltaire

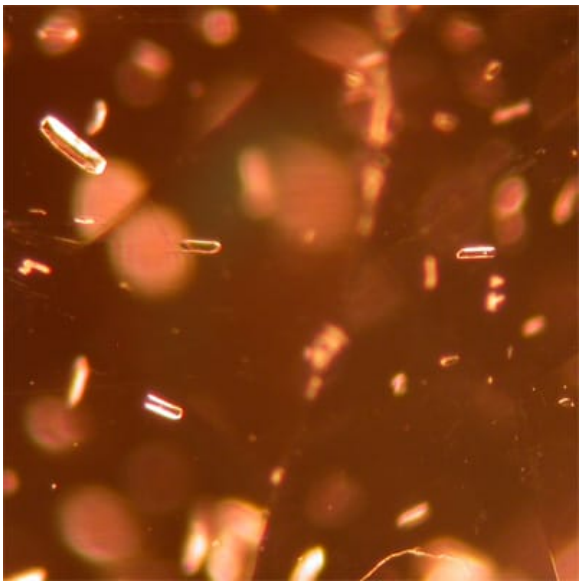


Figure 16.14.5***:*** *Tourmaline filled with negative crystals, oriented in random directions*
80X Magnification
by Barbra Voltaire



Figure 16.14.6***:*** *Growth Tubes in Pink Tourmaline*
~75X Magnification
by Jamey Swisher

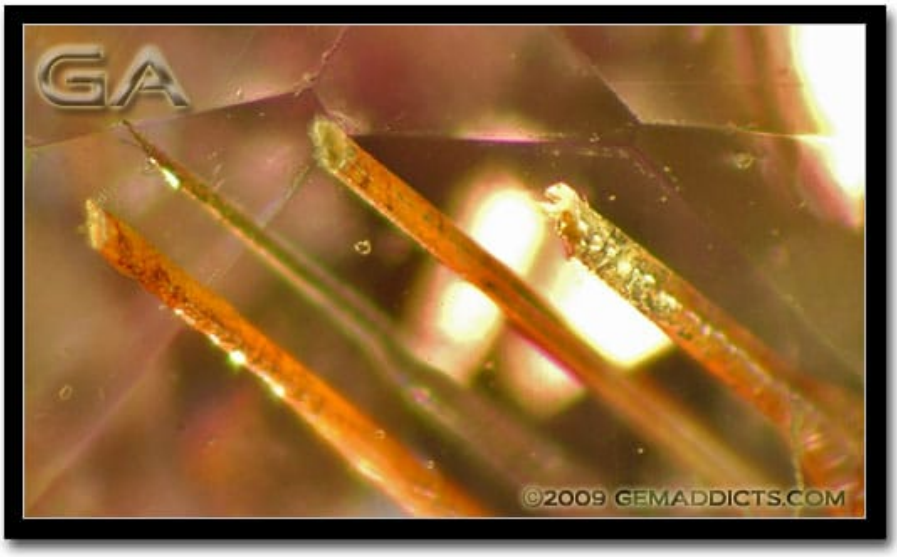


Figure 16.14.7***:*** *Ends of Growth Tubes in Pink Tourmaline*
~75X Magnification
by Jamey Swisher

Phenomena

- Cat's-eyes
- Color Change

An Unusual Variety of Color Change Elbaite ("Laurellite")

A variety of color change tourmaline has been collected and described by Bruce A. Fry.



Figure 16.14.8***:*** *Color Change Tourmaline*
Courtesy of Bruce Fry

Treatments

Tourmalines may be heat treated to around 700° C to lighten the color, this is a stable alteration.

A process which seems to work well for deep saturated reds from Nigeria involves slowly ramping the furnace at a rate of 125° C per hour to 520° C, holding the latter temperature for 2 hours and then letting the furnace cool completely.
A deep red Nigerian stone in the gallery below has been heat-treated several times as an experiment by Roger Dery with the ramping done last (following instructions by Lisa Elser on the latter part).



Figure 16.14.9***:*** *Nigerian red tourmaline. Heat treated at 360° C for 2 hours*



Figure 16.14.10***:*** *Heat treated at 410° C for 2 hours (same stone)*



Figure 16.14.11***:*** *Ramped up to 520° C over a three hour period. Held at 520° C for two hours, followed by cooling (same stone)*

Other treatments are irradiation - for example with cobalt-60 - (stable) and waxing of surface imperfections. The latter treatment is not stable.
Cobalt-60 gamma irradiation gives rise to pink and hot pink colors in some tourmaline.

Gallery of Tourmaline Crystals from Paraiba, Brazil

The following crystals were collected by Jason Barrett.
All specimens are from Sao Jose da Batalha mine in Paraiba State, Brazil.
Not all tourmalines from this mine were copper-bearing and these specimens have not been tested for copper content.



Figure 16.14.12***:*** *Crystal #1*
Weight: 88.4 grams
Measurements:5cm x 4cm x 3cm



Figure 16.14.13***:*** *Crystal #1*
Weight: 88.4 grams
Measurements:5cm x 4cm x 3cm



Figure 16.14.14***:*** *Crystal #2*
Weight: 314.1 grams
Measurements:7cm x 5.5cm x 4.5cm



Figure 16.14.15***:*** *Crystal #2*
Weight: 314.1 grams
Measurements:7cm x 5.5cm x 4.5cm



Figure 16.14.16***:*** *Crystal #3*
Weight: 268.8 grams
Measurements:10cm x 6cm x 4.5cm



Figure 16.14.17***:*** *Crystal #3*
Weight: 268.8 grams
Measurements:10cm x 6cm x 4.5cm



Figure 16.14.18***:*** *Crystal #3*
Weight: 268.8 grams
Measurements:10cm x 6cm x 4.5cm



Figure 16.14.19***:*** *Crystal #4*
Weight: 81.8 grams
Measurements:7cm x 4cm x 3cm



Figure 16.14.20***:*** *Crystal #4*
Weight: 81.8 grams
Measurements:7cm x 4cm x 3cm



Figure 16.14.21***:*** *Crystal #5*
Weight: 18.9 grams
Measurements:4.5cm x 2cm x 1cm



Figure 16.14.22***:*** *Crystal #5*
Weight: 18.9 grams
Measurements:4.5cm x 2cm x 1cm



Figure 16.14.23***:*** *Crystal #6*
Weight: 3.0 grams
Measurements:2cm x 1.5cm x 0.5cm



Figure 16.14.24***:*** *Crystal #6*
Weight: 3.0 grams
Measurements:2cm x 1.5cm x 0.5cm

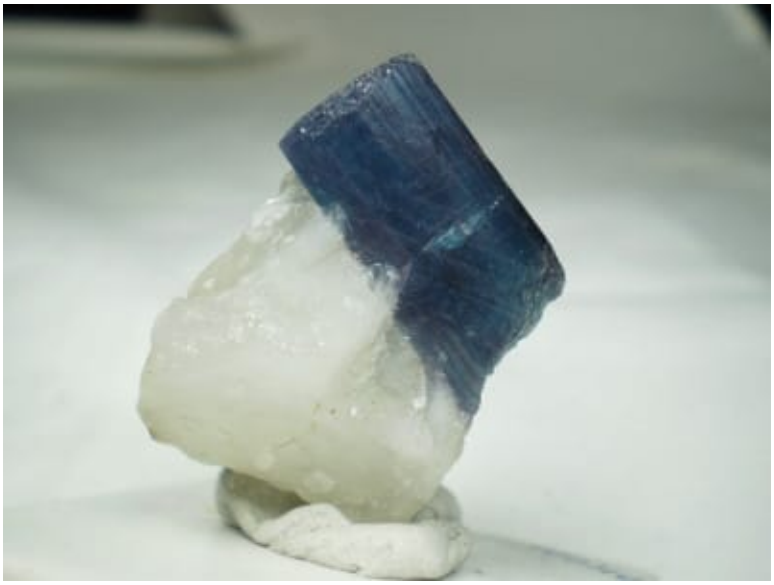


Figure 16.14.25***:*** *Crystal #7*
Weight: 24.4 grams
Measurements:3cm x 3.5cm x 2.5cm



Figure 16.14.26***:*** *Crystal #7*
Weight: 24.4 grams
Measurements:3cm x 3.5cm x 2.5cm



Figure 16.14.27***:*** *Crystal #8*
Weight: 52.9 grams
Measurements:5.5cm x 3.5cm x 2.5cm



Figure 16.14.28***:*** *Crystal #8*
Weight: 52.9 grams
Measurements:5.5cm x 3.5cm x 2.5cm



Figure 16.14.29***:*** *Crystal #9*
Weight: 54.8 grams
Measurements:7cm x 4cm x 1.5cm



Figure 16.14.30***:*** *Crystal #9*
Weight: 54.8 grams
Measurements:7cm x 4cm x 1.5cm



Figure 16.14.31***:*** *Parcel of Tourmaline*
Courtesy Jason Barrett

The parcel above was submitted by Jason Barrett for a microprobe analysis by UNO and the MP2 research group. The results are as follows:
SiO2:36.712%
Al2O3:42.221%
MnO:1.56%
CuO:1.471%
FeO:0.022%
MgO:0.000%
Na2O:2.365:
K2O:0.022%

F:1.182%
The 1.471 wt. % of CuO is just right in the range for the true Paraiba (Brazil) material

Sources

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- Red/Pink Tourmaline heat treatment
- Embrarad

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16.14.01: Liddicoatite

Rubellite Tourmaline	
Chemical composition	Complex Borosilicate
Crystal system	Trigonal
Habit	prismatic
Cleavage	none
Fracture	conchoidal
Hardness	7.5
Optic nature	uniaxial -
Refractive index	1.62 - 1.64
Birefringence	0.014 - 0.022
Dispersion	low, 0.018
Specific gravity	3.06
Lustre	Vitreous
Pleochroism	weak to strong

A German Film on Crystal Structure of Madagascar Liddicoatite

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16.14.02: Achroite

Achroite Tourmaline	
Chemical composition	Complex borosilicate
Crystal system	Trigonal
Habit	Prismatic
Cleavage	None
Fracture	Conchoidal
Hardness	7- 7.5
Optic nature	Uniaxial -
Refractive index	*1.62 - 1.64*
Birefringence	*0.014 - 0.040*
Dispersion	*Low, 0.017*
Specific gravity	*3.01 - 3.11*
Lustre	Vitreous
Pleochroism	Strong

$NaLi_{2.5}\ Al_{6.5}\ (BO_3)_3O_{18}(OH)_4$



Figure 16.14.2.1***:*** *Achroite Crystal, Pakistan*

Achroite is a the colorless variety of tourmaline which is usually (but not always) elbaite.

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16.14.03: Bi-color

Bi-color Tourmaline	
Chemical composition	Complex borosilicate
Crystal system	Trigonal
Habit	Prismatic
Cleavage	None
Fracture	Conchoidal
Hardness	7- 7.5
Optic nature	Uniaxial -
Refractive index	1.62 - 1.64
Birefringence	0.014 - 0.040
Dispersion	Low, 0.017
Specific gravity	3.01 - 3.11
Lustre	Vitreous
Pleochroism	Strong



Figure 16.14.3.1***:*** *Bi-color tourmaline*
Photo courtesy of Lembeck Gems

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16.14.04: Indicolite

Indicolite Tourmaline	
Chemical composition	Complex borosilicate
Crystal system	Trigonal
Habit	Prismatic
Cleavage	None
Fracture	Conchoidal
Hardness	7.5
Optic nature	Uniaxial -
Refractive index	1.62 - 1.64
Birefringence	0.014 - 0.022
Dispersion	Low, 0.018
Specific gravity	3.06
Lustre	Vitreous
Pleochroism	Weak to strong

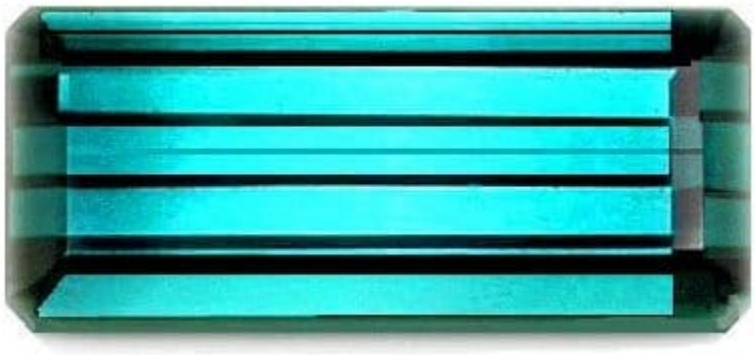


Figure 16.14.4.1***:*** *Indicolite Tourmaline*
Photo courtesy of Lembeck Gems

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16.14.05: Paraiba

Paraiba Tourmaline	
Chemical composition	Complex borosilicate
Crystal system	Trigonal
Habit	Prismatic
Cleavage	None
Fracture	Conchoidal
Hardness	7.5
Optic nature	Uniaxial -
Refractive index	1.62 - 1.64
Birefringence	0.014 - 0.022
Dispersion	Low, 0.018
Specific gravity	3.06
Lustre	Vitreous
Pleochroism	Weak to strong



Figure 16.14.5.1***:*** *Brazilian Paraiba tourmaline*
Photo courtesy of Lembeck Gems

Paraiba type



Figure 16.14.5.2***:*** *Mozambique "Paraiba-type" tourmaline 3.71 ct*
Photo courtesy of Precision Gem

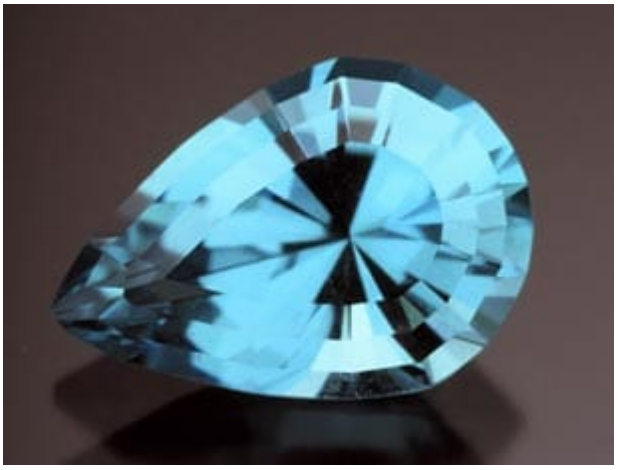


Figure 16.14.5.3***:*** *Nigerian "Paraiba-type" tourmaline, 1.53 ct*
Photo by Jeff Scovil
Courtesy of R.W. Wise Goldsmiths



Figure 16.1
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Ph
Courtesy

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16.14.06: Rubellite

Rubellite Tourmaline	
Chemical composition	Complex borosilicate
Crystal system	Trigonal
Habit	Prismatic
Cleavage	None
Fracture	Conchoidal
Hardness	7.5
Optic nature	Uniaxial -
Refractive index	1.62 - 1.64
Birefringence	0.014 - 0.022
Dispersion	Low, 0.018
Specific gravity	3.06
Lustre	Vitreous
Pleochroism	Weak to strong



Figure 16.14.6.1***:*** *Rubellite*
Photo Courtesy of Precision Gem

Rubellite is the pink to red color variety of tourmaline. The name can be applied to all species of the tourmaline group, but is generally elbaite.
"Rubellite" is a tradename and in modern teaching this is depreciated, instead it should be named red (or pink) tourmaline accompanied with the species name if determined.

Treatments

Pink tourmaline is sometimes irradiated to enhance the color to a deeper red.

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16.14.07: Tri-Color



Figure 16.14.7.1

Tri-color tourmalines come in just about every variety of color. Tri-color or multi-color tourmaline usually has 3 or more predominant colors present in the stone. Due to the fact that tourmaline are dichroic, they can appear to display many different colors all at the same time.

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16.15: Amber

Amber	
Chemical composition	C-H-O compound (fossil resin)
Crystal system	Amorphous
Fracture	Conchoidal, brittle
Hardness	2-2.5
Refractive index	1.54
Specific gravity	1.05-1.09
Lustre	Resinous

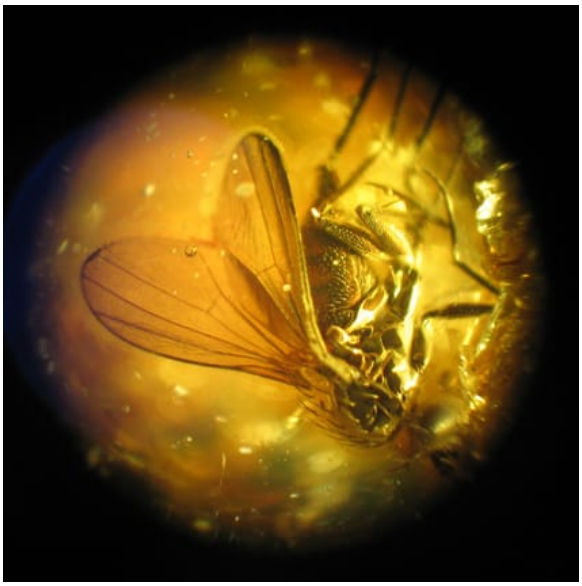


Figure 16.15.1***:*** *Baltic Amber with insect, Palmnicken (40-60 Million Years in age) Photo courtesy of Conny Forsberg*



Figure 16.15.2***:*** *Mexican amber*
Photo courtesy of Dave Gibson

Amber image gallery

Amber is the fossil resin from a pine tree that flourished in the Baltic region (and other localities) some 25 to 60 million years ago. Globs of this aromatic sap poured down from prehistoric trees, often trapping insects, twigs, bark and leaves. Amber is one of the few gemstones of organic origin. In ancient India and Egypt, amber was burned as an incense, believed to purify the surrounding area. Amber is abundant along the shores of the Baltic Sea where it is mined extensively from Tertiary glauconite sands that are from 40 million to 60 million years old.

Diagnostics

Amber is often very hard to separate from its imitations due to overlapping physical and optical properties. When no internal features are diagnostic, one can, usually, only fall back on destructive methods like the hot needle test and ether/acetone.

Color



Figure 16.15.3***:*** *Blue amber in reflected and transmitted light*

Amber occurs in the colors white, yellow, orange, red, brown, blue, black, green and has a typical resinous luster.

Blue and green amber is found only in the Dominican Republic. This blue (or green) color is only seen in reflected light, in transmitted light it will show a more common amber color (such as yellow, orange, red). Under UV light these blue gems give a strong cobalt blue fluorescence.
The cause of color of these blue and green gems is believed to be from fluorescence of UV and violet light from natural sunlight.

Delocalized electrons on organic molecules are the cause of the other colors.

Diaphaneity

Transparent to opaque.

Refractometer

Amber has a refractive index of ~1.54 and is singly refractive.
Copal and some plastics are in the same range of amber gemstones.
Glass and chalcedony also have a similar refractive index to amber.

Specific gravity

The specific gravity varies from 1.05 to 1.09. Amber with many gas bubbles is in the lower range.
Amber floats in a saturated saline solution. This is the reason why amber is found on many shores around the Baltic Sea, it floats on sea water.
As with the refractive index, copal and some plastics fall in the same range.

Hot needle test

When a needle is heated and then brought to a piece of amber, it will give a pine tree odor, while the plastic simulants will smell like burned plastic.

Ether

When a small drop of ether or acetone is placed on plastic or copal, it will leave a sticky surface while they have no effect on real amber.

Polariscope

Amber is singly refractive and will show anomalous extinction (ADR) and stress colors between crossed polarizers, as will some plastics.

Magnification

- Insects (usually extinct species) and other flora and fauna that got trapped by the resin.

  (These can be mimicked in plastic)

Electricity

The Greek word for amber is "electron" and "electricity" is named after this gemstone.

When rubbed with silk, amber will get a negative electric charge while glass will be positively charged.
Plastics will also be charged negatively like amber.

Treatments

Heat treatment

A lot of amber contains many gas bubbles that give it a hazy appearance. Slow heating between 150-180° C, followed by slow cooling, can diffuse these bubbles out.
When the cooling takes place too rapidly, typical leaf-like stress inclusions form (these are known as "sun spangles") and these inclusions are, more than often intentionally, mistaken for prehistoric leaf inclusions.

Another type of heating involves laying the specimens in a sand-filled iron pot and heat it over an extensive period to darken the amber. This gives it an "antiqued" look. Natural amber may darken naturally over time due to air oxidation.

Other treatments

- Dying
- Coating
- Foiling

Imitations

Reconstructed amber

One type of amber that one may encounter is reconstructed amber. This type of amber is also marketed as "ambroid".
Clear fragments of amber are carefully selected and heated up to ± 180° C under high pressure of +350 bar in a reducing atmosphere with sometimes linseed oil added. Under these conditions, the fragments fuse together and some organic dyes may be added to the process to influence the color of the resulting solid block.
These gemstones may whiten over time opposed to naturally occurring amber which will darken.

The following inclusions may be seen:

- flow lines
- elongated bubbles

A strong bright blue fluorescence might be observed.

Copal

Copal is also a natural occurring fossilized resin which can also be artificially created. The resin has been buried in the earth for a considerably shorter period and its hardness is lower than that of amber.
The best way of descriminating between copal and amber is by placing a small drop of ether or acetone on the gemstone. This will create a sticky surface on copal, while it has no effect on amber. This is a destructive method though.
The fluorescence of copal is much whiter than that of amber.

Plastic

Plastic is often used to imitate amber. Even complete insects and/or small animals like salamanders are embedded into the mold to mimic natural fauna inclusions.
When the hot needle test is applied to them, it will smell acrid instead of piney.

If you are offered a piece of amber with a complete salamander at low cost, there must be something wrong as they would fetch several ten-thousands of dollars when genuine.

Occurrence

Mexico

Mexican Amber* Amber is a fossilized resin that exuded from the bark of an ancient long extinct tree. It is not the same as sap which is a nutrient for the tree rising through the heartwood. The ambers antiseptic properties protect the tree from disease and attacks from wood gnawing and burrowing insects. As it exuded as blobs or stalactites which drip or flow down the trunk or branches of the tree. the resin acted as a sticky trap entombing flora and fauna.

This amber with inclusions is a natural time capsule. The best pieces capturing a moment in time from millions of years ago. Most amber is from the Baltic region or from the Dominican Republic. Mexican amber, often also known as Chiapas amber is from Mexico's most southern state which borders Guatemala. It brings a much-needed income to some of the poorest people in Mexico. It is quite rare. The mining is very much a cottage industry. The indigenous Tzotzil Mayan tunnel and burrow into the mountainside using simple hand tools. The mining is somewhat seasonal when they are not working on the maze or coffee crop. Sometimes the production can be in total a few kilos a day.

From the latest research, it appears that Mexican amber is from the Oligocene/Miocene in age some 24-30 million years ago. This amber is natural not treated like most Baltic amber. It often has a lovely fluorescence to it and produces good natural red amber. Though it was known to the ancient Maya and traded to the Aztecs and other tribes. The Spanish conquistadors tell of the Aztec Emperor Montezuma stirring his chocolate with an amber spoon. It was first introduced to the modern world by the eminent archaeologist Franz Blom. Blom was born in 1893 in Copenhagen into a middle-class Danish family. He was restless and traveled to Mexico. He found work in the oil industry as a paymaster. Traveling to remote locations in the Mexican jungle he became interested in the Mayan ruins he encountered. He obtained a degree in archaeologist from Harvard University. He helped document many ancient Mayan archaeological sites and discovered the ancient Mayan site of Uaxatun. He was one of the foremost experts on Mayan archeology and culture. He became aware of amber deposits in the Simojovel area of Chiapas and sent samples with insect inclusions to the University of California.

This sparked off such interest that soon after in 1953 a group of scientists from California's Museum of Paleontology, Berkeley arranged with Blom to visit the amber deposits in the Simojovel area. Blom owned a large house in the Spanish colonial town of San Cristobal de las Casas. It was a cultural and artistic center. They set off with Blom in a jeep for Simojovel in the Chiapas highlands. This was something like a 60-mile journey on a dirt road that winded through the mountains. They experienced many difficulties with landslides and rock falls etc. Added to that the local indigenous were not used to outsiders and were often hostile. Despite the problems, the expedition was successful. Stratographic mapping was undertaken. Amber with inclusions was obtained. One new find was a new species of a stingless bee. The most significant collection of Mexican amber is at the University

of California Museum Berkeley. It was assembled by PD Hurd Jnr and other scientists in the 1950's. My first visit to Simojovel was in 1974-75. It was still an isolated area and hard to get to.

It was Dr. George Poinar's research work into DNA in amber inclusions which gave Michael Crichton his idea for the book Jurassic Park. On the day of the film release of Jurassic Park, Dr. Poinar and his team of scientists announced that they had made a breakthrough in extracting DNA from an extinct bee in Dominican amber. This set off much interest in the inclusions in amber. I do not know why anyone would want to create a dinosaur. But it has resulted in beneficial research work into plants and insects in amber and to the development of modern species.

Copal versus amber
The distinction between Copal and amber is contentious as they both have the same chemical formula. The difference is Copal contains liquids such as oils acids and alcohol. These produce the distinct resin smell. It is often used in incense. In amber, these volatile liquids have dissipated and evaporated. The resin has then undergone a process known as polymerization. The organic molecules join to form larger ones called polymers. The molecules are cross-linked and intertwined. In Copal, only part polymerization has taken place.

The chemical formula for Copal and amber is pretty much the same. From a chemical and geological point of view, some people claim no distinction should be made between copal and amber just generally classify them as resinites or fossil resin. Other people insist they should all be called amber. From a jewelry and gemological point of view, the definition has to be on its physical properties. Copal still contains volatile liquids which evaporate thus causing it to crack and craze. Copal is not rare and it is unstable and not as hard and durable as amber.

According to Dr. George Poinar, Columbian Copal ranges in age from ten to a few hundred years old. African and Madagascan Copal are probably the same age. The oldest Copal is probably from New Zealand (better known as Kauri gum) which can be up to 40,000 years old. The inclusions in amber are of extinct insect species. In Copal they are modern species.

The best test for distinguishing amber from Copal is a drop of solvent or acetone nail polish remover. Copal will become sticky whilst it will have no effect on amber.

Conclusion
Inclusions in amber have enabled scientists to research the Earth's climatic change patterns and evolution and development of flora and fauna.

Much research has been done on inclusions in Baltic amber going back over a long period of time. Baltic amber has been almost fully researched. Even Dominican amber has been more researched than Mexican Amber probably because Mexican Amber is rare and hard to obtain. I have supplied 16 pieces of Mexican amber for research into the inclusions. One contained a new species and genus of insect which was named after me - Tonacatecutlius Gibsoni.

Mexican and Dominican amber are not as old as Baltic amber though the inclusions in Mexican and Dominican are probably just as important, if not more, as they come from a time when modern-day plants and insects were evolving in the Oligocene/Miocene period.

- The areas around the Baltic Sea (Poland, Denmark, Finland, Sweden, Germany, Latvia, Lithuania)
- The Dominican Republic
- Borneo Island (Sarawak and Sabah in Malaysia, Kalimantan in Indonesia, Brunei Darussalam)
- North America (New Jersey, Arkansas, Alaska, Montana, North Carolina in the USA)



Figure 16.15.4***:*** *Chiapas Amber,*
Very suitable for jewelry as it's hold the polished surface longer enough. Mined from the lignite deposit at the Simojovel, Chiapas, Mexico



Figure 16.15.5***:*** *Borneo Amber,*
Toughest and uniform forms of Borneo amber from Merit-Pila Coal Mine, Sarawak, Malaysia



Figure 16.15.6***:*** *Borneo Amber,*
Toughest and uniform forms of Borneo amber from Sabah, Malaysia



Figure 16.15.7***:*** *Borneo Amber,*
Very brittle and semi-transparent forms of Borneo amber from Sabah, Malaysia



Figure 16.15.8***:*** *Golling amber,*
Rarely cut as cabochon because of its extreme rarity. Although Golling amber is very old resin(125 million years old), it sometimes has gem-quality properties and also harder than normal amber.



Figure 16.15.9***:*** *Lee Creek Amber,*
Very difficult to polish and usually keep in raw forms. Have similar properties to Borneo amber. It was found at PCS, North Carolina in the active phosphate mine.



Figure 16.15.10***:*** *New Jersey Amber,*
Very brittle Cretaceous amber. It is found near the Sayreville, New Jersey, USA

In Memory of David Gibson and His Passion for Amber

Mexican Mayan Amber

Sources

- *Gemstone Enhancement* (1984) - Kurt Nassau ISBN 0408014474
- Gems Their Sources, Descriptions and Identification *4th Edition (1990) - Robert Webster (6th ed.)*
- *Gem Reference Guide* (1995) - GIA ISBN 0873110196
- **Dave Gibson* http://www.mexicanamber.org.uk

External links

- A 2½ minute video about blue amber in the Dominican Republic
- A video on the basics of electricity and magnetism by Prof. Walter Lewin

G&G Articles on Amber 1934-1980

The GIA has published all the G&G's from 1934 until 1980 online. The organization of the list by subject was done by Joseph Gill.

- Spring 1943, **Amber**, by Briggs, p. 78, 3pp
- Fall 1959, **A pink amber-like resin from Southern Calif**., p. 337, 2pp.
- Fall 1963, **A Painted Amber**, p. 87, 1p
- Winter 1964, **Pressed Amber**, p. 243, 2pp.
- Winter 1965, **Pressed Amber**, p. 370, 2pp.
- Summer 1966, **Coated Amber**, p. 60, 1p.
- Winter 1967, **Amberdan (amber imitation)**, p. 251, 2pp.
- Summer 1968, **Amber Fraud (large spider in amber doublet)**, p. 318, 2pp.
- Summer 1969, **Coated Amber**, p. 67, 1p.
- Fall 1970, **Varnished Amber (to improve color)** , p. 227, 1p.
- Spring 1971, **Amber Snuff Bottles**, p. 276, 2pp.
- Fall 1972, **Amber with many insect inclusions**, p. 93, 2pp.

- Winter 1972, **Pressed Amber and Natural Amber**, p. 116, 1p.
- Winter 1973, **Natural amber chips in a plastic**, p. 251, 2pp.
- Winter 1976, **bugs in plastic imitation of amber**, p. 251, 1p.
- Winter 1978, **Amber from the Dominican Republic**, p. 367, 3pp.
- Fall 1978, **Baltic Amber**, by Gübelin, p. 66, 11pp.

Museums

- Esbjerg Museum, Esbjerg, Denmark.

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16.16: Ammolite

Ammolite	
Chemical composition	$CaCO_3$ with trace elements
Crystal system	Orthorhombic
Habit	Fractured and non-fractured flat layers
Fracture	Parting along layers
Hardness	3.5
Refractive index	1.525 - 1.670
Birefringence	0.135 - 0.145
Specific gravity	2.60 - 2.85
Lustre	Vitreous to resinous

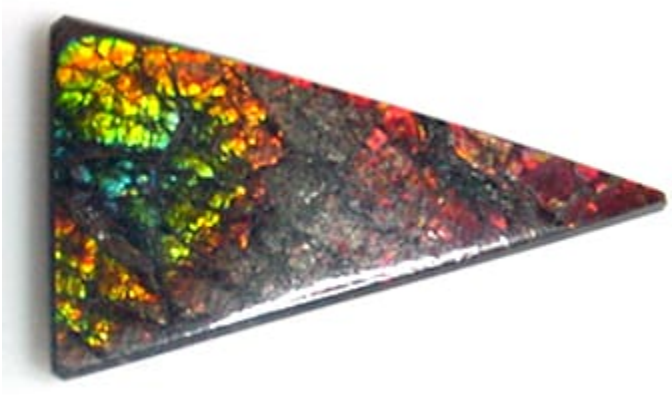


Figure 16.16.1***:*** *Triangular Ammolite Cabochon; Photo courtesy of Barbra Voltaire*

Ammolite is the iridescent gem variety of a unique fossil ammonite, currently excavated only in southern Alberta, Canada. Ammonites are an extinct marine animal that first appeared 400 million years ago and became extinct at the end of the Cretaceous Period, 65 million years ago.
Natural ammolite has a hardness of 3.5, but is most often sold as a doublet or triplet in order to protect the gem material. Natural stones are often impregnated with an epoxy as a treatment to strengthen the ammolite.
Color comes from the interference of light, and it is dependent on the thickness of the layers of aragonite. From thickest to thinnest: red, green, blue, and purple.
The color play is a result of iridescence (interference).

Sources

- *Ammolite: Iridescent Fossilized Ammonite* .. - Keith A. Mychaluk et all.- Gems & Gemology (Spring 2001)

External links

- Gem Society - Ammolite

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16.17: Anatase

Anatase	
Chemical composition	TiO_2
Crystal system	Tetragonal
Habit	Dipyramidal
Cleavage	Perfect
Fracture	Sub-conchoidal
Hardness	5.5 - 6 (brittle)
Optic nature	Uniaxial -
Refractive index	2.488 - 2.561
Birefringence	0.073
Specific gravity	3.89
Lustre	Adamantine/metallic



Figure 16.17.1

Sources

- Anatase at Mindat.org

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16.18: Andalusite

Andalusite	
Chemical composition	Al_2SiO_5
Crystal system	Orthorhombic
Habit	Prismatic
Cleavage	Distinct
Fracture	Sub-conchoidal
Hardness	7.5
Optic nature	Biaxial -
Refractive index	1.63-1.64
Birefringence	0.010
Dispersion	Low, 0.016
Specific gravity	3.18
Lustre	Vitreous
Pleochroism	Very strong



Figure 16.18.1***:*** *Andalusite*
Photo courtesy of Distinction Jewelry



Figure 16.18.2***:*** *Location: Sierra Albarrana, Cordoba, Spain*

Andalusite is a little known and much underappreciated gem. It is highly pleochroic, meaning that it appears to be different colors depending upon from which direction the stone is viewed. The most common colors are a bronzed red coupled with a golden green. Although it is often referred to as "poor man's alexandrite" because of the tone of its pleochroic colors, it actually does NOT have the ability to change colors like alexandrite does. Andalusite is named after Andalusia, the province of Spain where it was first discovered. It is said to stimulate memory and recollection. Not only recent memory, but it is actually attributed with the ability to make one able to remember their past lives.

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16.19: Apatite

Apatite	
Chemical composition	$Ca_5(PO_4)_3(F,Cl,OH)$
Crystal system	Hexagonal
Habit	Prismatic
Cleavage	Imperfect, basal
Fracture	Conchoidal
Hardness	5
Optic nature	Uniaxial -
Refractive index	1.63-1.64
Birefringence	0.003
Dispersion	Low, 0.013
Specific gravity	3.2
Lustre	Vitreous
Pleochroism	Weak



Figure 16.19.1***:*** *Faceted Apatite*
Photo courtesy of The Gem Trader



Figure 16.19.2***:*** *Unusual Violet Faceted Apatite*
Photo courtesy of Jason Brim

Apatite is named "the deceiver" as it's color, refractometer and specific gravity readings are similar to gemstones as tourmaline, topaz, andalusite and danburite.

Diagnostics

Appearance

Apatite occurs in yellow, green, violet, purple, blue, brown, colorless and pink and can be transparent to translucent.

Optic Character

DR, Uniaxial negative

Refractometer

Refractometer readings are in the range of tourmaline, topaz, andalusite and danburite but usually with a very low birefringence of 0.003.
Full range: n_ω = 1.629 - 1.667 and n_ε = 1.624 - 1.666 with a full birefringence of 0.001-0.007.

Spectroscope

The spectroscope is a good diagnostic tool in separating apatite from gemstones as tourmaline and topaz.

Blue apatite will, usually, show a rare earth spectrum line in the blue (praseodymium).
Blue-green stones may have added spectrum lines in the yellow (didymium) and line(s) in the green (praseodymium).
Yellow gems show the rare earth spectrum of greenish-blue without the line in the blue.
Neon blue stones may show rare earth spectra in the yellow.

UV Reactions

- Blue: Blue to light blue (LW and SW)
- Yellow: Purplish Pink (stronger in LW)
- Green: Greenish-yellow (stronger in LW)
- Violet: Greenish-yellow (LW); Light purple (SW)

Chelsea Colour Filter

Green-blue stones: green

Dichroscope

Apatite has weak pleochroism, so this tool may not be very useful except for blue stones where the dichroism is more profound (blue and pale yellow).

Polariscope

A nice uniaxial negative interference figure should be found.

Primary Sources

Brazil, Burma, Mexico
Violet and Purple are found in Maine and Afghanistan.

Magnification

Clouds of tiny white crystal inclusions may be easily observed.

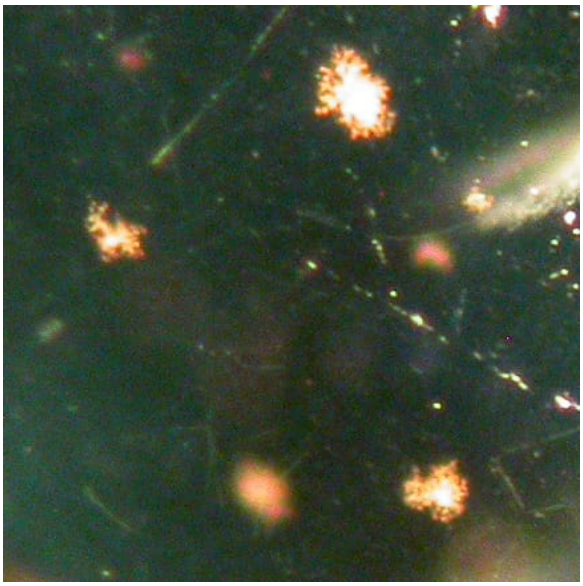


Figure 16.19.3***:*** *Blue apatite with crystalline "fireworks" of an unidentified mineral*
40X Magnification
by Barbra Voltaire

F

Phenomena

- Cat's-eyes

G&G Articles on Apatite 1934-1980

The GIA has published all the G&G's from 1934 until 1980 online. The organization of the list by subject was done by Joseph Gill.

- Summer 1962, **Cat's-eye apatite**, p. 315, 2pp.
- Summer 1963, **Yellow cat's-eye apatite**, p. 44, 1p.
- Winter 1965, **Cat's-eye apatite**, p. 372, 1p.
- Summer 1966, **A cat's-eye apatite of 220 cts.**, p. 46, 1p.
- Winter 1972, **Rare Earth Absorption Spectra in Apatite**, by Anderson, p. 101, 1p.
- Winter 1972, **A 40 ct. cat's-eye apatite**, p. 114, 1p.

Sources

- *A Students' Guide to Spectroscopy* (2003) - Colin Winter FGA, DGA ISBN 0954485300
- Introduction to Optical Mineralogy *3rd edition (2003), Prof. W.D. Nesse*

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16.20: Axinite

Axinite	
Chemical composition	Complex borosilicate
Crystal system	Triclinic
Habit	Axe shaped.
Cleavage	Perfect {100}
Fracture	Uneven to conchoidal, brittle
Hardness	6.5 - 7
Optic nature	Biaxial - (or +)
Refractive index	1.674 - 1.706
Birefringence	0.010 - 0.012
Dispersion	Low, 0.018 - 0.020
Specific gravity	3.27-3.29
Lustre	Bright vitreous
Pleochroism	Moderate to Strong



Figure 16.20.1***:*** *A pinkish/greenish brown axinite.*
Photo courtesy of Chaman Golecha, Gem Testing Laboratory, Jaipur.

Chemical composition

$Ca_3Al_2BSi_4O_{15}(OH)$. Much variation in composition due to replacement of Ca by Fe, Mg, Mn. Therefore the composition may be written as $(Ca, Mn, Fe, Mg)_3Al_2BSi_4O_{15}(OH)$

- +Mg - magnesioaxinite
- If Fe more than Mn - Ferroaxinite

- If Mn more than Fe - Manganaxinite
- If Mn more than Fe and Ca less than 1.5 - tinzenite

Crystallography

Triclinic.
Habit: broad and acute edged usually (axe shaped); varied habit; Also massive, lamellar, granular, curved. Generally in clusters, also tabular.

Diagnostics

Color

Clove Brown, rarely honey yellow or plum blue. Also pearly gray, greenish yellow; violet-brown; colorless-yellowish(Mn); pale violet/reddish (Mn), blue (Mg).

Diaphaneity

Transparent to semi transparent.

Hardness

7-6.5 (directional)

Specific gravity

3.27-3.29 [Ferroaxinite:3.17-3.31; Magnesioaxinite:3.18; range 3.26-3.36]

Refractometer

Optic Character: anisotropic; Biaxial Negative (If high in Mg may turn +ve).
R.I.: n_α = 1.674-1.693, n_β = 1.680-1.701 and n_γ = 1.684-1.706.
Generally R.I.:1.67 to 1.68
Maximum birefringence: 0.010 - 0.012

Spectrum

Strong bands at 512, 494, 466 and sometimes 415nm; strong lines at 523, 444.

Luminescence

UV fluorescence: May show red-orange under SWUV

Pleochroism

Strong depending on body colour and source. Generally olive green/violet blue and cinnamon brown.

Simulants

- Andalusite: Lower S.G., spectrum, R.I. etc
- Barite: Higher heft, lower hardness

- Smoky Quartz: Lower Heft (floats 2.88), bulls-eye optic figure, R.I. etc
- Sphene: Doubling, dispersion, spectrum

Occurrence

Geological occurrence:
Occurs in cavities of granite or diabase; contact zones

Geographical locations:
Good crystals from St. Cristophe, France; various American localities; Bahia, Brazil; Cornwall, England; Mexico; Also in California; Sri Lanka; Nevada (masses); New Jersey; Germany; Norway; Finland; USSR; Japan; Tasmania; Switzerland (Tinzenite); Tanzania (Magnesoaxinite); Sri Lanka (ferro axinite-cinnamon brown)

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16.21: Azurite

Azurite	
Chemical composition	$Cu_3(CO_3)_2(OH)_2$
Crystal system	Monoclinic
Habit	Short columlar, botryoidal
Cleavage	Indistinct
Fracture	Conchoidal, uneven, brittle
Hardness	3 1/2 - 4
Optic nature	Biaxial +
Refractive index	1.720-1.848
Birefringence	0.108-0.110
Specific gravity	3.7-3.9
Lustre	Vitreous
Pleochroism	Light blue, dark blue



Figure 16.21.1***:*** *Botryoidal Azurite*
Bisbee, Arizona

Azurite forms directly from the oxidation of copper ore. Azurite (blue) and malachite (green) are often found together because azurite tends to alter into malachite. Because of azurite's intense blue color, it was once used as a pigment for oil paints. Unfortunately, time has caused those originally blue skies and bodies of water to go decidedly green. In ancient Egypt, azurite paint was used by temple priests to paint and decorate the Third Eye on their foreheads believing that it increased their powers. The ancient Chinese revered azurite as the Stone of Heaven, able to open spiritual doorways.

Localities

- dark blue almost black crystals have come from Tsumbed (Namibia) and Morocco

- Australia (Queensland), Chile, Mexico, Russia (Ural) and United States (Arizona, New Mexico)

Sources

- *Gemstones of the world* - Walter Schumann

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16.22: Barite

Barite (Baryte)	
Chemical composition	$BaSO_4$
Crystal system	Orthorhombic
Habit	Tabular parallel to base, fibrous, nodular to massive
Cleavage	Perfect cleavage parallel to base and prism faces: {001} Perfect, {210} Perfect, {010} Imperfect
Fracture	Irregular/uneven
Hardness	3-3.5
Optic nature	biaxial +
Refractive index	nα = 1.634–1.637 nβ = 1.636–1.638 nγ = 1.646–1.648
Birefringence	0.012
Specific gravity	4.3–5
Lustre	Vitreous to pearly
Diagnostic Features	High specific gravity, characteristic cleavage and crystals



Figure 16.22.1***:*** *Faceted Barite 19.35cts.*
Courtesy of Egor Gavrilenko

Barite,($BaSO_4$) is a mineral consisting of barium sulfate. It is generally white or colorless, and is the main source of barium.
It is never used in jewelry because of it's extremely low hardness and distinct cleavage, which makes it very difficult to fashion as a gem.
Barite (spelled baryte in British publications) was named from the Greek word baros which means weighty, a reference to its unusually high specific gravity.
It can occasionally be found in esoteric gem collections as a rare curiosity.



Figure 16.22.2***:*** *Barite Crystals with Calcite, Locality: Northumberland, Nye County, NV Collection of Barbra Voltaire*

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16.23: Benitoite

Benitoite	
Chemical composition	$BaTiSi_3O_9$
Crystal system	Trigonal
Habit	Bipyramids
Cleavage	None
Fracture	Conchoidal
Hardness	6.5
Optic nature	Uniaxial +
Refractive index	1.75-1.80
Birefringence	0.047
Dispersion	High, 0.046
Specific gravity	3.65
Lustre	Bright vitreous
Pleochroism	Strong

Benitoite is a very rare mineral that was discovered in 1907 in San Benito County in California. It has never been found elsewhere. It was originally mistaken for sapphire. Benitoite is very highly dispersive (the ability to take white light and disperse it into various components of the spectrum) with an adamantine luster when polished.
Benitoite is associated with other rare minerals such as black-red neptunite, snow white natrolite, and brown-yellow joaquinite. Since the only source of this rare combination occurs at San Benito County, California, it has been designated the California state gemstone. Crystals, and cut stones tend to be small and quite expensive!



Figure 16.23.1***:*** *Photo Courtesy of Rob Lavinsky*



Figure 16.23.2***:*** *Photo Courtesy of Barbra Voltaire*

Spectrum



Figure 16.23.3***:*** *4mm faceted benitoites, Colorless to Dark Blue*
Photo Courtesy of Barbra Voltaire

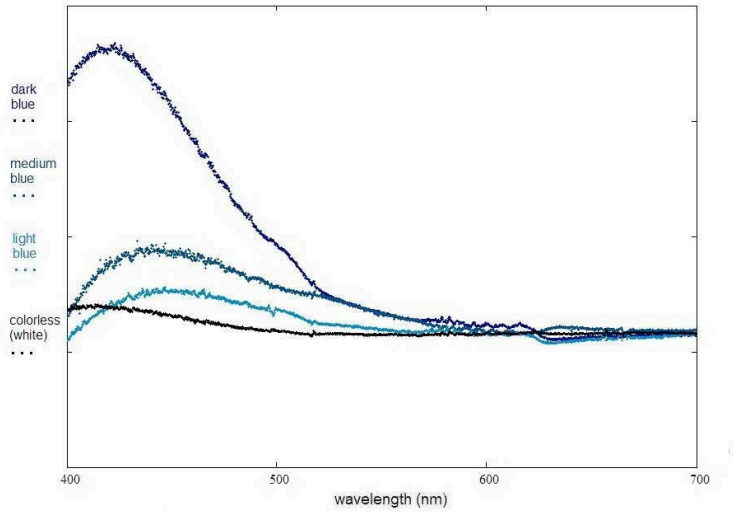


Figure 16.23.4***:*** *Transmission Spectrum*
The more saturated the blue, the higher the peak in the 400-500 nm range

Cause of Color

The origin of color in benitoite has not been definitively established.
Proposed ideas include:
Fe2+ - Ti4+ or the Fe2+ - Fe3+ intervalance charge transfer.

While most benitoite is colorless when viewed down the c-axis, there is a very small number (3) of exceedingly rare stones (now cut into gemstones) which are pink in this direction.

The Benitoite Gem Mine

The Early Days: An Interview with Ed Swoboda and Peter Bancroft

G&G Articles on Benitoite 1934-1980

The GIA has published all the G&G's from 1934 until 1980 online. The organization of the list by subject was done by Joseph Gill.

- Summer 1953, **Benitoite**, by Ehrmann, p. 317, 1p.
- Summer 1963, **A beautiful 4 1/2-ct. benitoite and a colorless benitoite**, p. 55, 1p.
- Spring 1968, **Pink benitoite from Calif**., p. 284, 2pp.
- Spring 1968, **Benitoite Inclusions**, p. 285, 2pp.

Additional Information

Dr. Edward Gübelin Collection: Benitoite

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16.24: Bowenite

Bowenite (Serpentine)	
Chemical composition	$Mg_6((OH)_8)Si_4O_{10})$
Crystal system	Mostly monoclinic
Habit	Cryptocrystalline
Cleavage	None
Fracture	Even to hackly
Hardness	2-5.5
Optic nature	None
Refractive index	±1.55
Birefringence	None
Dispersion	None
Specific gravity	2.59
Lustre	Waxy
Pleochroism	None

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16.25: Calcite

Calcite	
Chemical composition	$CaCO_3$
Crystal system	Hexagonal(Trigonal)
Habit	Massive
Hardness	3
Specific gravity	2.69 - 2.71
Optic nature	Uniaxial -
Refractive Index	1.486 - 1.658
Birefringence	0.172 - 0.19
Lustre	Vitreous

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16.26: Charoite

Charoite	
Chemical composition	Complex potassium silicate
Crystal system	Monoclinic
Hardness	7 - 7.5
Optic nature	Biaxial -
Refractive index	1.545 - 1.560
Specific gravity	2.66 - 2.68

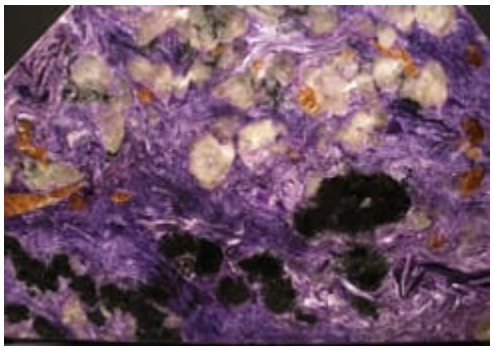


Figure 16.26.1***:*** *Charoite*

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16.27: Clinohumite

Clinohumite	
Chemical composition	Magnesium silicate
Hardness	6
Optic nature	Biaxial +
Refractive index	1.628 - 1.674
Birefringence	0.024 - 0.041
Specific gravity	~ 3.21
Lustre	Vitreous
Pleochroism	Strongly trichroic
Fluorescence	SWUV: strong orange yellow LWUV: generally inert



Figure 16.27.1***:*** *A 9.45 ct brownish orange clinohumite tested at the Gem Testing Laboratory, Jaipur.*

Clinohumite is a member of the humite group. As a gemstone it is rare, but some cut stones are reported. The given below details are (largely) abstracted from Journal of Gemmology, 2007, 30, 5/6, 303-306 "A remarkably large clinohumite".

Crystallography

Monoclinic

Diagnostics

Color

Bright yellow-orange color resembling some hessonite and spessartine garnets.
Cause of color: Mn

Diaphaneity

Transparent

Refractometer

Clinohumite has a biaxial optic character with a positive optic sign.
The refractive index range of clinohumite: n_α = 1.628 - 1.638, n_β = 1.641 - 1.654, n_γ = 1.662 - 1.674.
The maximum birefringence ranges from 0.024 to 0.041.

For a specific stone tested (9.45 ct. brownish orange clinohumite tested at the Gem Testing Laboratory, Jaipur): R.I.: 1.646-1.670, birefringence: 0.024.

Pleochroism

Strong trichroism: yellow, orange and brownish yellow.

Specific gravity

S.G.: ~ 3.21

Spectrum



Figure 16.27.2***:*** *Diffraction spectrum*

Brownish-orange clinohumite.
General cut-off till 430nm (from 400nm).

Luminescence

SWUV: strong orange-yellow;
LWUV: generally inert

Magnification

Inclusions: Strong color and growth zoning, flat parallel reflective planes, fluid-like inclusions similar to trichites in tourmaline. Such liquid inclusions along with doubling appear very much like tourmaline; tube like inclusions; sometimes swirly zones.

Occurrence

Geographical occurrence: Gem quality Clinohumite is known to occur in two important localities - The Pamir mountains (at Kukh-i-lal, Sumdzin and Changin); in Tajikistan in association with spinel and in the Taymyr region (Basin of Kotui river) in Siberia; Also in Mahenge, Tanzania.

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16.28: Copal

Copal	
Chemical composition	Fossilized, semi-fossilized resin
Crystal system	**Amorphous**
Habit	**None, Amorphous**
Cleavage	**None**
Fracture	**Uneven-Conchoidal**
Hardness	**2**
Refractive index	**1.540 (-0.010)**
Specific gravity	**1.06 (+.04,-.03)**
Lustre	**Resinous**
Separations	**Amber:** Copal is rapidly attacked with acetone (2-3 seconds) whereas amber is usually not affected or just slightly attacked in the same period of time



Figure 16.28.1***:*** *Kauri gum, New Zealand (20,000 - 36,000 years in age)*

Copal is a tree resin fossil which is much younger than amber and is sometimes used as an amber simulant. Copal can be referred in many ways. It is believed that copal is somewhere between 50 years to 1.6 million years, based on the geological environment in which it is found, coupled with other criteria, both chemical and botanical. Occasionally there will be insects present within copal, but these insects are NOT extinct species! Experts have concluded that the resin which created copal probably originated from tropical legume and araucarian trees.

Copal image gallery

Age

The age of copal can vary from 50 years to 1.6 million years in age. It can be considered a semi-fossilized resin or an immature amber.

Diagnostics

Copal constants are similar to amber but is softened by ether.
Its surface is crazed and is very sectile (crumbles easily under the knife blade).
To conclusively separate copal from other resins, such as amber, often involves sophisticated chemical analysis and biological determinations, but there are several methods one can use if they do not have access to these techniques, expertise and instruments. Good clues involve the setting in which the specimen is found, fluorescence, SG, acetone and hot point. With the exception of SG and fluorescence, testing may harm the piece. Proceed cautiously.

Magnification

Copal occasionally contains insects, but these insects are not extinct species.

Occurrence

Copal is mainly found in East Africa and South America, primarily tropical latitudes.



Figure 16.28.2***:*** *Colombian copal,*
South American copal (Usually 250 years in age)

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16.29: Coral

Coral	
Chemical composition	Aragonite ($CaCO_3$)or conchioline
Crystal system	Amorphous
Habit	Branching, tree-like
Hardness	2.5 - 3.5
Refractive index	1.48 - 1.56
Specific gravity	1.37 - 2.60
Lustre	Waxy



Figure 16.29.1***:*** *Mediterranean Red Coral Beads*



Figure 16.29.2***:*** *Coral, Species: Scleronephthya*

Coral is one of the few organic gems. It is the exoskeleton of colonial polyps. These are small animals that create their branching homes from calcium carbonate dissolved in seawater. The colors of gem coral range from pale pink (angel-skin) to oranges and reds. Coral has been used throughout our history; it was pictured on a Sumerian vase dated at 3000 BC It was traded between the Mediterranean and India at the time of the birth of Christ. Coral was introduced into Mesoamerica by the Spaniards. Native Americans used it extensively in jewelry. Coral was used in Roman times to protect children from danger. It is still worn in Italy today to protect from the evil eye.

G&G Articles on Coral 1934-1980

The GIA has published all the G&G's from 1934 until 1980 online. The organization of the list by subject was done by Joseph Gill.

- Spring 1950, **Coral, the Forgotten Gem**, by Copeland, p. 282, 6pp.
- Fall 1959, **Black Coral of Hawaii**, p. 337, 1p.
- Fall 1960, **Black Coral of Hawaii**, p. 72, 3pp.

- Summer 1962, **A White Coral Substitute**, p. 304, 2pp.
- Spring 1967, **Black coral characteristics**, p. 146, 1p.
- Fall 1967, **Dyed Angel-Skin Coral**, p. 209, 1p.
- Summer 1973, **A partly silicified coral**, p. 182, 2pp.
- Fall 1973, **Hawaiian Black Coral**, by Webster, p. 196, 3pp.
- Fall 1973, **Silicified Coral**, p. 206, 2pp.
- Fall 1973, **Lapidary of Black Hawaiian Coral**, p. 232, 1p.
- Winter 1974, **Blue Coral**, p. 369, 2pp.
- Winter 1974, **Hawaiian black coral, but with a golden sheen**, p. 369, 3pp.
- Summer 1979, **An Examination of the New Gilson "Coral,"** by K. Nassau, p. 179, 7pp.
- Winter 1979, **Gold Corals – Some Thoughts on Their Discrimination**, by Grahame Brown, p. 240, 5pp.

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16.30: Danburite

Danburite	
Chemical composition	$CaB_2(SiO_4)_2$alcium boro-silicate
Crystal system	Orthorhombic
Habit	Prismatic
Cleavage	Indistinct, basal
Fracture	Sub-conchoidal
Hardness	7.0-7.5
Optic nature	Biaxial +/-
Refractive index	1.630-1.636
Birefringence	0.006
Dispersion	low, 0.017
Specific gravity	3.00
Lustre	Vitreous
Pleochroism	Weak/not determinable
Fluorescence	Light blue (LW)

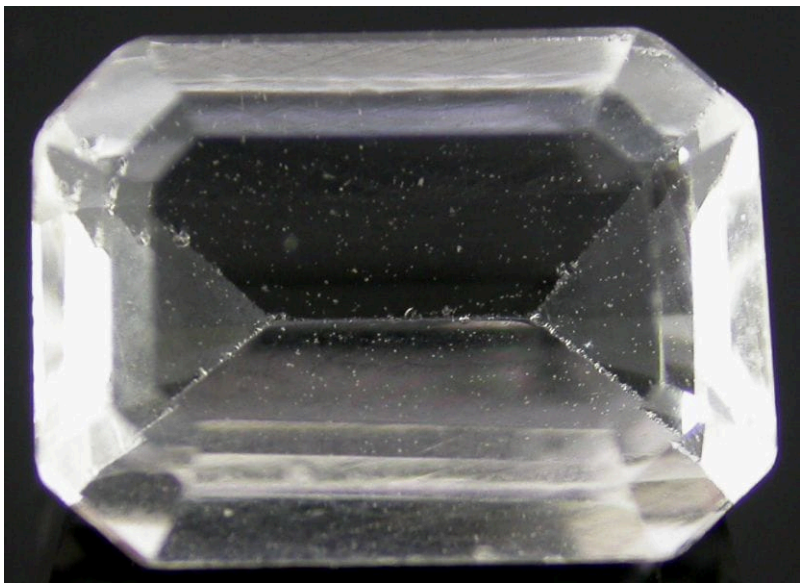


Figure 16.30.1***:*** *A colorless danburite.*
Photo courtesy of Chaman Golecha

Danburite was named for the town of Danbury, Fairfield County, Connecticut, where it was first reported in 1839. This initial discovery was of no gemological interest, but by 1880, an additional occurrence in Russell, St Lawrence County, New York was producing facetable rough. Although danburite is now known from many localities around the world, only a few have produced material of sufficient clarity to be facetted.

Chemical composition

Calcium boron silicate, $CaB_2(SiO_4)_2$, sometimes with minor to trace amounts of iron, manganese, sodium, and magnesium.

Diagnostics

Danburite may be confused with topaz, tourmaline, andalusite and apatite.

Color

Colorless to pale pink; golden yellow, yellow-brown.

Refractive index

Danburite is biaxial with either a negative or a positive optical sign, depending on the wavelength of the light source. For sodium light (n_D) it will be negative. The use of blue light will give a positive optical sign.
Beta is halfway between alpha and gamma.

Refractive index: n_α =1.630, n_β =1.633, n_γ =1.636.
Birefringence: 0.006

Topaz will have lower readings in RI but a higher birefringence.

Specific gravity

The SG range of danburite goes from 2.93 to 3.02 (mean = 3.0) and it will float in heavy liquids 3.06 and 3.33 while andalusite will sink in 3.06 and topaz will sink in both.

Fluorescence

The majority of danburites fluoresce a blue-white color in longwave ultraviolet radiation. This must not, however, be considered wholly diagnostic.

Spectroscope

Danburite may show a rare earth spectrum due to didymium (lines in the yellow).

Treatments

Danburite may turn pink on irradiation.

Occurrence

Danburite occurs in pegmatites and in carbonate rocks that have been metamorphosed and exposed with hydrothermal activity.

Large quantities of water-clear to pale-pink danburite have been obtained from Charcas, San Luis Potosí, Mexico since the late 1950's; Mogok, Mandalay Division, Myanmar (Burma), has produced rough exhibiting a very pleasing straw-yellow or golden color; and distinctly golden-brownish to straw yellow to amber-yellow rough has been obtained from the Anjanabonoina pegmatites and the Madagascar Sahatany Pegmatite Field and other sites in Antananarivo Province, Madagascar. Sherry to golden colored danburite rough has been produced from Dal'negorsk (Dalnegorsk), Primorskiy Kray, Russia.

Sources

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16.31: Datolite

Datolite	
Chemical composition	$CaB[OH\|SiO_4]$
Crystal system	Monoclinic
Habit	Short prisms, porcelaneous cryptocrystalline aggregates
Cleavage	None
Fracture	Conchoidal to uneven
Hardness	5 - 5.5
Optic nature	Biaxial -
Refractive index	1.622 - 1.670
Birefringence	0.044
Specific gravity	2.95 - 3.0
Lustre	Vitreous to porcelainous

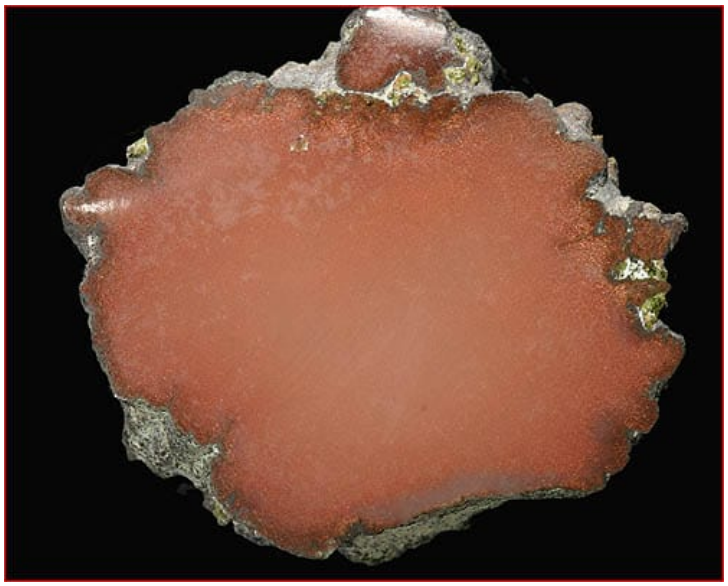


Figure 16.31.1***:*** *Datolite from the Caledonia Mine, Mass City, Michigan*

Datolite was named 1806 by Professor Jens Esmark from the Greek “to divide,” referring to the granular structure of the first specimens studied from Arendal, Norway.

Chemical composition

Calcium boron silicate hydroxide, CaBSiO4(OH) with minor to trace amounts of iron, manganese, and aluminum.

Diagnostics

Color

Crystals are colorless to white, often with a pale green or greenish yellow tint. Massive datolite is translucent to opaque grayish, reddish, pink, brown or yellow.

Refractive index

Optical nature and sign: biaxial negative
Refractive Index: n_α = 1.622 – 1.626 n_β = 1.649 – 1.654 n_γ = 1.666 – 1.670

Magnification

Massive datolite from Michigan cut en cabochon sometimes exhibits microscopic inclusions of native copper. The copper has sometimes oxidized to give the rough a copper-green color.

Occurence

Small quantities of greenish yellow to colorless datolite faceting rough have been produced at Dal'negorsk (Dalnegorsk), Primorskiy Kray, Russia. In addition to faceting rough, there was a largely unsuccessful attempt about 2002 to introduce a skarn rock composed of wollastonite and datolite to the US lapidary market; the material is marked by alternating bands light and dark olive-green bands and swirls. The skarn was apparently also produced in Primorskiy Kray (Dalnegorsk?). Compact, porcelain-like masses of datolite, some as large as 30cm in diameter and of a pleasing brown, red, yellow, malachite-green, white or grey color,, have been recovered since the mid-19th century from dozens of mines in Houghton, Keweenaw, and Ontonagen counties in Michigan's famed "Copper Peninsula." Rough is still being recovered by reworking abandoned mine dumps as well as scuba diving off the coastline.

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External links

- Keneewa Michigan field trip
- Lapidary additional

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16.32: Diaspore

Diaspore	
Chemical composition	AlO(OH)
Crystal system	Orthorhombic
Habit	Tabular, sometimes fibrous
Cleavage	Perfect to imperfect
Fracture	Conchoidal
Luster	Bright vitreous to pearly (on cleavage surface).
Hardness	6.5 - 7
Optic nature	Biaxial +
Refractive index	1.682 - 1.752
Birefringence	0.040 - 0.048
Specific gravity	3.2 - 3.5
Lustre	Vitreous
Pleochroism	Moderate



Figure 16.32.1***:*** *Color-changing diaspore from green in daylight to brown in incandescent light - also known as “Zultanite” in the gem market.*
Photo courtesy of Chaman Golecha, Gem Testing Laboratory, Jaipur.

Diaspore as a plausible gemstone has been reported first around 1977 when a large enough crystal was examined at the Gem Testing Laboratory in London. This, usually colorless, material showed good color-change from pale bluish-green to pale pinkish-brown. Turkey was the origin of this color-change material. When Zultanite Gems LLC acquired the mining location, this color-change variety of diaspore was marketed under the tradename "zultanite®". At present (2007) sole distribution rights of "zultanite®" are granted to GemsTV.

Chemical composition

AlOOH + Mn (or Fe) as impurity (a dimorph of boehmite).
Mn or Fe may substitute Al in the lattice.

Crystallography

Orthorhombic.
Habit: crystals are elongated plates (tabular); acicular needles also massive; foliated.

Diagnostics

Diaspore may be confused with peridot due to the strong doubling of back facets, but diaspore is usually much paler in color. Iron-rich green sapphire has an absorption spectrum close to diaspore.

Color

Colorless, pale bluish-green to pale green, pale pinkish-brown to pale brown.

Diaphaneity

Transparent to opaque.

Specific Gravity

S.G.:3.2 - 3.5 (mean = 3.4)

Cleavage

Perfect in one direction {010} and imperfect on {110} and {210}.

Refractometer

Optic nature: Biaxial positive.
Refractive index range: n_α = 1.682 - 1.702, n_B = 1.705 - 1.725 and n_γ = 1.730 - 1.752. Mean = 1.702 - 1.750.
Maximum birefringence: 0.040 - 0.048.

Spectrum

Not diagnostic but Turkish stones 471, 463, 454 (much similar to iron-rich sapphire).

Luminescence

UV fluorescence: May show dull pale yellow (LW) and green (SW)

Pleochroism

Strong depending on body color and source. Blue / Pale green and rose to dark red.

Magnification

Diaspore is a type II stone on the GIA clarity scale, hence small inclusions are usually found.

Phenomena

- Color-change
- Cat's-eyes

Simulants

Sapphire	No strong doubling of facets; higher heft; higher R.I., unixial figure.
Sillimanite	Lower S.G., lower RI and lower birefringence.
Peridot	Lower RI and slightly lower birefringence.

Occurrence

Geological occurrence:
In metamorphosed limestones, chloritic schists and altered igneous rocks. Also in bauxite deposits.

Geographical locations:
Memaris, Turkey (gemmy pale brown); Chester, Massachusetts (with corundum); Pennysylvania (fine transparent colourless to brown); Hungary; South Africa in Postmasburg district - Manganiferous variety; Cornwall, England; Greenland; Norway; Sweden; France; Switzerland; Germany; Greece; USSR; Japan; China; Turkey.

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16.33: Dioptase

Dioptase	
Chemical composition	$CuSiO_3H_2O$
Crystal system	Trigonal
Habit	Prismatic
Cleavage	Perfect, rhombohedral
Fracture	Conchoidal to uneven
Hardness	5
Optic nature	Uniaxial +
Refractive index	1.644 - 1.709
Birefringence	0.053
Dispersion	Medium, 0.030
Specific gravity	3.28 - 3.35
Lustre	Vitreous
Pleochroism	Weak



Figure 16.33.1***:*** *Faceted Dioptase*
Photo courtesy of The Gem Trader

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16.34: Ekanite

Ekanite	
Chemical composition	$ThCa_2Si_8O_{20}$
Crystal system	Tetragonal
Habit	Elongated, pebbles.
Cleavage	None
Hardness	6 - 6.5
Optic nature	Uniaxial -
Refractive index	1.560 - 1.596
Birefringence	0.001-0.008
Dispersion	Low
Specific gravity	3.28
Lustre	Vitreous



Figure 16.34.1***:*** *A green radioactive ekanite.*
By Chaman Golecha, Gem Testing Laboratory, Jaipur.

Crystallography

Tetragonal system.
Habit: crystals are elongated parallel to the optic axes. Massive as pebles. A rare crystalline non-metamict state of ekanite has also been found.

Chemical composition

$ThCa_2Si_8O_{20}$: Calcium Thorium Silicate with radioactive elements present. Commonly Uranium, Iron, Lead also present. Metamict

and rarer non-metamict ekanite has been found.

Diagnostics

Color

Green, dark brown, light brown, emerald green, also chatoyant, 4-ray, 6-ray varieties also. Straw yellow when pure; dark red (due to inclusions).

Diaphaneity

Transparent to translucent.

Specific gravity

S.G. 3.08 (impure) and 3.28 - 3.36 (pure) generally 3.28

Refractometer

Optic Character: DR, Uniaxial negative.
Refractive index: 1.560 - 1.568 (may also be 1.590-1.596 or 1.573-1.572) Most commonly 1.596
Maximum birefringence: 0.001 - 0.008

Ekanite may test isotropic due to metamictization.

Spectrum

May show lines at 630, 658 nm

Luminescence

UV fluorescence: generally inert

Inclusions

Crystalline inclusions

Other properties

Radioactive; enough to activate a Geiger Muller Counter. Non-radioactive material also found. May test isotropic due to radioactivity.

Phenomena

Chatoyancy and asterism (4 or 6-pointed stars).

Treatments

Heat treatment to restore crystalline state.

Simulants

Brazilianite: lower S.G.; R.I., D.R.

Occurrence

Geological occurrence:
Found as water-worn pebbles; first in the gem-gravels of Sri Lanka. Also in glacial syenitic boulder.

Geographical locations:
Ehiliayagoda, near Ratnapura in Sri Lanka; Also chatoyant, 4- or 6-ray also. Also at Mt. Ste Hilare; Quebec, Canada; Central Asia; Tombstone mountains, Canada (non-metamict ekanite).

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16.35: Enstatite

Enstatite

Enstatite	
Chemical composition	(Mg,Fe)SiO_3agnesium silicate
Crystal system	Orthorhombic
Habit	Crystals and waterworn pebbles
Cleavage	Distinct
Fracture	Sub-conchoidal
Hardness	5.5
Optic nature	Biaxial +
Refractive index	1.65-1.68
Birefringence	0.010
Dispersion	Low, 0.010
Specific gravity	3.3
Lustre	Vitreous
Pleochroism	Strong to moderate

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16.36: Fluorite

Fluorite	
Chemical composition	CaF_2alcium fluoride
Crystal system	Cubic
Habit	Octahedral, cubes, interpenetrant twins
Cleavage	Perfect, octahedral
Fracture	Conchoidal
Hardness	4
Optic nature	Isotropic
Refractive index	1.434
Birefringence	Isotropic
Dispersion	Very low, 0.007
Specific gravity	3.18
Lustre	Poor vitreous
Fluorescence	Bluish-white, purple (LW)



Figure \(\PageIndex{1}\): *Fluorite with Barite and Galena*
Elmwood Mine, Carthage, Tennessee



Figure \(\PageIndex{2}\): *Fluorite with Sphalerite and Barite*
Elmwood Mine, Carthage, Tennessee



Figure 16.36.3***:*** *Faceted purple fluorite*



Figure 16.36.4***:*** *Green Fluorite*
Westmoreland, New Hampshire



Figure 16.36.5***:*** *Faceted Green Fluorite; 229 carats*



Figure 16.36.6***:*** *Fluorite*



Figure 16.36.7***:*** *Yellow Fluorite Crystals*
Clay Center, Ohio

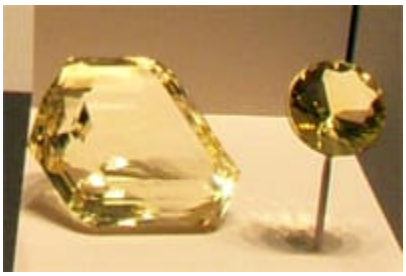


Figure 16.36.8***:*** *Yellow Fluorite Faceted*
847.4 carats and 84.7 carats



Figure 16.36.9***:*** *Yellowish Green Fluorite*

Diagnostics

Thermoluminescence

Fluorite may luminesce when heated. The stored energy from UV radiation is released if heated to a certain temperature and the

effect depends on the amount of stored energy.
One can see this when a small amount of fluorite is placed on a teaspoon and heated over a candle for a few minutes (in a dark room).
Material from Telemark, Norway will show a blue-green thermoluminescence.

Optical phenomena

Color change

Color change fluorite has been reported with a change from blue to purple (much like some color change garnet).

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16.37: Obsidian

Obsidian (named after the roman, Obsius) is a volcanic glass.

Diagnostics

Color

Its color is black, grey, brown, green and can be gold or silver due to inclusions.

Diaphaneity

Transparent to opaque.

Hardness

Obsidian has a hardness of 5-5 1/2.

Specific gravity

Obsidian has a density of 2.35-2.60.

Refractive index

Obsidian is singly refractive with an R.I. range of 1.45 to 1.55.

Varieties

- Snowflake obsidian is the trade name for an obsidian with grey-white, ball shaped inclusions of Spherulites found in Mexico and the United States.

Localities

Deposits are found in the United States, Mexico, Japan, Italy, Iceland, Indonesia, and Equador.

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16.38: Goldstone

A man-made material usually cut en cabochon. Goldstone consists of minute tetrahedral crystals of copper dispersed in glass. It is created by the melting of glass containing copper salts in a reducing (oxygen depleted) environment, causing the copper salts to decompose to metallic copper. Goldstone has been produced in reddish-brown, blue, purple and green colors; the color of the first is a result of the finely disseminated copper crystals, while the color in the latter three resulting from changes in the body color of the glass surrounding the microscopic copper crystals.

Goldstone was developed by Vincenzo Miotti, a member of a prominent family of Venetian glassmakers, in the late 17th century. Keeping with the tradition of the medieval craft-guild, the formulation was maintained a closely guarded secret. It was not until the early 19th century, after the family had stopped making glass, that it was divulged by one of the surviving members of the family. A litany of apocryphal “urban folklore” mythologies regarding how and when Goldstone was created have devolved (rather than evolved). Foremost among these is that it was accidently discovered by Italian monks (religious order unknown) when they dropped copper shavings into a batch of molten glass in the 19th century (or 18th century. Or 17th century). Another more apotropaic claim has been advanced that “Goldstone” was the result of medieval alchemists’ search to create gold.

Synonyms: “Aventurine glass”

Diagnostics

Goldstone could be confused for aventurine quartz and sunstone.

Aventurescence

The glittery, glimmering appearance caused by the reflection of light by internal particulate inclusions in both rough and cut stones – is the hallmark of goldstone.

Luster

Greasy.

Fracture

Conchoidal to subconchoidal.

Refractive Index

1.53

Specific Gravity

Variable from 2.50-2.80

Magnification

Gas bubbles are sometimes evident. The uniform shape and size of the copper crystals as well as the uniform distribution of the copper crystals through the glass body helps differentiate goldstone from aventurine quartz and sunstone. The copper crystals in goldstone are readily visible under 20x magnification. The crystals may appear more silvery than coppery red in the blue, purple and green variations of Goldstone as a result of the filtering effects of the colored glass comprising the body of the material. Large masses of rough may sometimes preserve flattened contact surfaces, rounded edges, and surfacial flow lines that were created when the molten glass was poured out onto a hard surface to chill.

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16.39: Hauyne

Hauyne	
Chemical composition	Complex silicate
Crystal system	Cubic
Habit	Dodecahedral
Cleavage	Poor
Hardness	5.5 - 6
Optic nature	Isotropic
Refractive index	1.494 - 1.509
Birefringence	None
Specific gravity	2.44 - 2.50
Lustre	Vitreous to greasy



Figure 16.39.1***:*** *Faceted hauyne, 0.26ct*



Figure 16.39.2***:*** *Small faceted Hauyne*
Eifel District of Germany

Photo courtesy of Barbra Voltaire

Haüyne (pronounced "how-een") is an extremely rare mineral and even rarer gemstone. It was first described, mineralogically in 1807 by René Hauy from who it derived its name. Examples of haüyne are found in association with alkaline volcanic rocks that are primarily located in the vicinity of Laacher See Eifel Mountain district of Germany. The highest prized specimens of Haüyne found in this locality are of an unusual vibrant blue color. Lighter blue to greenish blue colors are found as well. Gem quality material has not been reported from other localities.

Hauyne's spectrum is diagnostic in the darker blue specimens with a full absorption of the red to green.

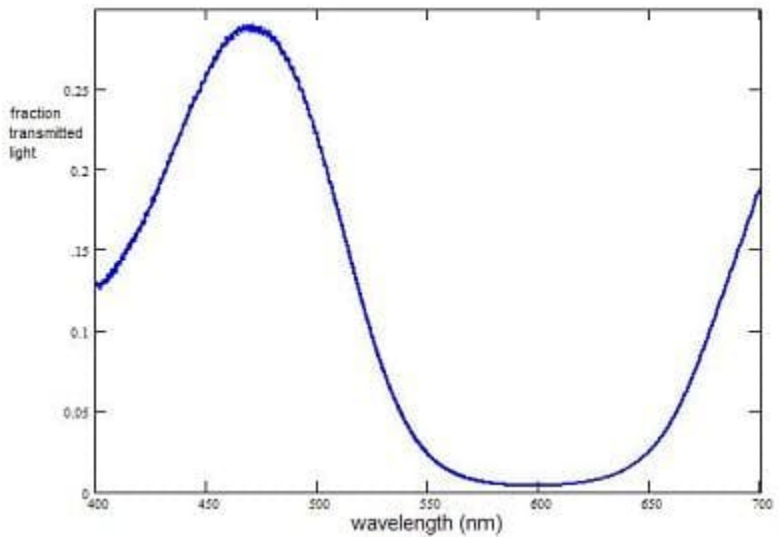


Figure 16.39.3

The lighter specimens fluoresce an intense orangy pink under LWUV.

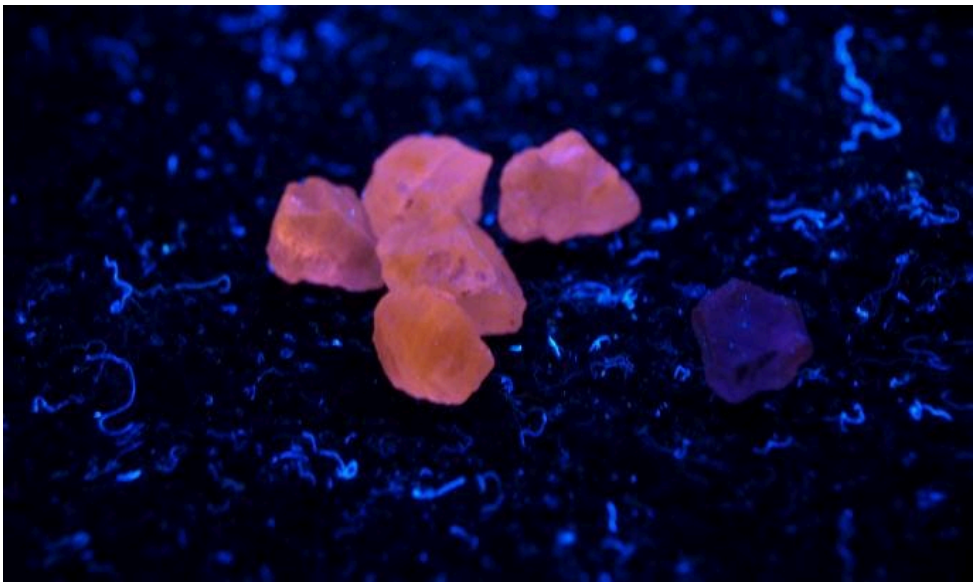


Figure 16.39.4

Note the inert stone on the right which is a slightly darker blue hauyne

Geology

Haüyne, in the Eifel Mountains, formed in a magma chamber, with other minerals which include plagioclase, sanidine, nosean, nepheline, leucite, apatite, olivine and in association other alkaline volcanic rocks, mainly phonolites. It is thought that this eruption occurred 12,900 years ago (geologically a wink of the eye) in three layers. Haüyne occurs in all three layers. The area is commercially mined for pumice and basalt. Hauyne can be collected in these quarries during the weekends.



Figure 16.39.5***:*** *Hauyne Crystals*

Additional Information

Dr. Edward Gübelin Collection: Hauyne

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16.40: Hematite

Hematite

Hematite	
Chemical composition	Fe_2O_3
Crystal system	Trigonal
Habit	Tabular to thick crystals; micaceous or platy, commonly in rosettes; radiating fibrous, reniform, botryoidal or stalactitic masses, columnar; earthy, granular, oolitic
Cleavage	None, may show partings on {0001} and {1011}
Fracture	Uneven to sub-conchoidal
Hardness	5.5–6.5
Refractive index	n_ω = 3.150–3.220, n_ε = 2.870–2.940
Specific gravity	5.26
Lustre	Metallic

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16.41: Iolite

Iolite	
Chemical composition	Complex Mg-Al (magnesium aluminum) silicate
Crystal system	Orthorhombic
Habit	Massive, prisms
Cleavage	Distinct, basal
Fracture	Sub-conchoidal
Hardness	7.5
Optic nature	Biaxial -
Refractive index	1.53 - 1.55
Birefringence	0.008 - 0.012
Dispersion	Low, 0.017
Specific gravity	2.58 - 2.74
Lustre	Vitreous
Pleochroism	Strongly trichroic



Figure 16.41.1***:*** *Marquise Shaped Faceted Iolite, courtesy of Richard Kocerek.*

Iolite is also named "water sapphire", cordierite or dichroite. Iolite has been worn for centuries and derives its name from “Ios” - the Greek word for violet. It is often claimed, that due to its strong pleochroism, ancient Vikings used iolite for navigation on cloudy days. It is conjectured that the gemstone acted as a polarizing filter and allowed the ancient sailors to determine the position of the sun. Although this is a widely published story, there is no empirical archaeological evidence that actually supports it.
The soft blue color makes it a very attractive gemstone. Iolite is the 21st anniversary gemstone.

Iolite is a color variety of the mineral cordierite. Sometimes the name "cordierite" is used to indicate "iolite".
The green variety of cordierite is named praseolite.

Diagnostics

Iolite may be confused (due to its color) with sapphire and tanzanite.

Color

Iolite is usually blue to violetish-blue. Rarely it is colorless.

Magnification

Iolite is a type II stone in the GIA clarity grading system is usually included. Typical inclusions are:

- liquid feathers
- hexagonal platelets of biotite, hematite or pyrrothite

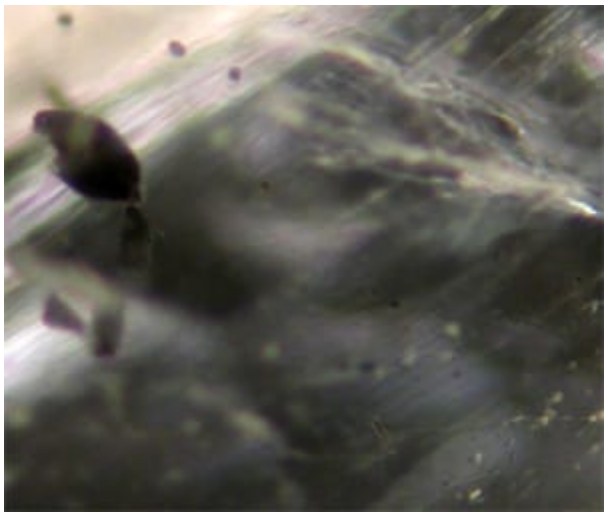


Figure 16.41.2***:*** *Hexagonal platelets, liquid feathers*
60X Magnification
By Barbra Voltaire

The iolite pictured above features liquid feathers, internal cleavage planes, and randomly oriented hexagonal platelets, possibly biotite or pyrrothite.

Optical and physical properties

Although iolite is usually confused with sapphire and tanzanite due to its color, its optical properties will distinguish iolite from them easily.

Pleochroism

Iolite is very strongly trichroic and this is the primary test in separating iolite from other gemstones. The three colors you will find are through dichroscopic examination are:

1. violet-blue
2. pale-blue
3. pale yellow

Sapphire is dichroic and although unheated tanzanite is also trichroic like iolite, the heated tanzanite is dichroic. Natural unheated tanzanite is very rare.

Refractometer

Iolite is biaxial with a negative optic sign. The β ray is almost halfway between α and γ so precise readings should be taken.
A typical reading will be n_α = 1.535-1.539 and n_γ = 1.540-1.543
The maximum birefringence ranges from 0.008 to 0.012
Tanzanite is also biaxial but has a positive optic sign and its values are too high to indicate iolite. Sapphire is uniaxial and the readings are also too high.

Quartz has RI readings in the range of iolite, but is uniaxial.

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16.42: Jade

Jade is the general name given to two gemstones, jadeite and nephrite. Despite that they may be similar in appearance, the two minerals have little else in common. The term "jade" does not refer to a specific mineral but is rather a historical term used for both jadeite and nephrite when sophisticated separation techniques were not available.

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16.42.01: Jadeite

Jadeite	
Chemical composition	$NaAl(SiO_3)_2$
Crystal system	Monoclinic
Habit	Polycrystalline
Fracture	Flintery
Hardness	6.5 -7
Specific gravity	3.30 - 3.37
Lustre	Greasy to vitreous

Jadeite is made up of interlocking pyroxene crystals. It occurs in a vary wide range of colors like green, lilac, white, pink, brown, red, blue, black, orange and yellow. The most prized color is a rich emerald green and is called Imperial Jade. Its green color is due to its chromium content and can be distinguished with a Chelsea (jadeite) filter. Jadeite is believed to prevent/cure hip and kidney ailments.

Enhancements

Common enhancements to jadeite:

- Fracture filling - wax - conceal cracks and fractures
- Coatings - wax - to improve luster
- Staining - color improvement through dyes
- Bleaching - removes stains
- Polymer impregnation - improves luster and to stabilize piece after bleaching

Occurrence

The most important source of jadeite is Myanmar but Guatemala, Japan and the USA (California) are also important sources

Sources consulted

- Smithsonian Handbooks, Gemstones, Second Edition 2002

G&G Articles on Jade 1934-1980

The GIA has published all the G&G's from 1934 until 1980 online. The organization of the list by subject was done by Joseph Gill.

- March-April 1934, **Jadeite thought found in America (Oregon)**, p. 54, 1p.
- [www.gia.edu/research-resources/gems-gemology/back-issue-archive/May-June-1934.pdf">May-June 1934, **Jade**, p. 80, 3pp.
- May-June 1934, **Red Jade, by M. Ehrmann**, p. 84, 1p.
- Fall 1944, **Nephrite found in Lander**, Wyo., in 1936, p. 170, 1p.
- Fall 1948, **Jade Carving in China**, p. 82, 5pp.
- Spring 1950, **Jadeite and nephrite found in Calif.**, p. 289, 1p.
- Summer 1951, **Jadeite and nephrite found in Calif., and artifacts**, p. 76, 3pp.
- Spring 1952, **Jade in Mexico**, p. 147, 5pp.
- Summer 1954, **The Nature of Ja**de, p. 38, 9pp.

- Fall 1956, **Jadeite from San Benito County, Calif.,** p. 331, 4pp.
- Fall 1960, **Jade Cutting Today**, p. 81, 9pp.
- Winter 1964, **"Pigeon eye" nephrite from Wyoming** (shows chatoyant spots), p. 251, 2pp.
- Summer 1966, **Taiwan jade (nephrite)**, p. 62, 1p.
- Spring 1976, **Jade, China's Contribution to Fine Art**, by A. Alexander, p. 145, 8pp.
- Fall 1979, **Clarification of Composition of Maw Sit Sit**, p. 217, 2p.
- Summer 1980, **Australia Likely To Be Major Supplier of Jade**, by J. Stone, p. 331, 1p.
- Summer 1943, **So-called "Mexican jade" is calcite**, p. 87, 1p.
- Winter 1955, **Cat's-eye nephrite**, p. 238, 1p.
- Spring 1958, **Jadeite triplets**, p. 134, 3pp.
- Winter 1961, **Jadeite "Yunnan Jade" from Burma** (showing absorption spectrum), p. 242, 2pp.
- Spring 1962, **Rare gray-blue jadeite**, p. 283, 1p.
- Winter 1963, **Faded dyed jadeite**, p. 100, 2pp.
- Summer 1964, **Stable color in dyed jadeite**, p. 181, 1p.
- Winter 1965, **Dyed nephrite first seen at the GIA**, p. 363, 2pp.
- Winter 1965, **A new type of jadeite triplet (two pieces of jadeite, green coloring in center)**, p. 369, 2pp.
- Winter 1967, **Dyed jadeite**, p. 245, 1p.
- Summer 1969, **Glass jade imitation**, p. 58, 2pp.
- Winter 1970, **Glass-like jade imitation**, p. 249, 3pp.
- Summer 1971, **Dyed lavender jadeite**, p. 323, 2pp.
- Summer 1972, **Jade substitute (glass)**, p. 44, 2pp.
- Summer 1972, **Jade-like minerals**, p. 50, 3pp.
- Fall 1972, **Distinguishing burial jade from burned jade not yet possible**, p. 83, 2pp.
- Fall 1972, **Paraffin-treated jade**, p. 84, 2pp.
- Fall 1972, **Blue jade-like material (tremolite)**, p. 91, 2pp.
- Fall 1972, **A cat's-eye yellow jadeite**, p. 93, 1p.
- Winter 1972, **Testing dyed antique replicas of j**ade, p. 112, 1p.
- Winter 1972, **Jade cat's-eye (?),** p. 113, 1p.
- Spring 1973, **Jade imitations in devitrified fibrous glass (meta jade, Imori stone)**, p. 134, 2pp.
- Summer 1973, **Durability of jadeite vs. nephrite**, p. 175, 2pp.
- Fall 1973, **Treated lavender jadeite**, p. 214, 2pp.
- Fall 1974, **Unevenly dyed jadeite**, p. 350, 1p.
- Spring 1975, **A "meta jade" glass with spectrum of natural jadeite**, p. 27, 2pp.
- Fall 1975 **Rare, nearly transparent, light gray faceted jadeite**, p. 73, 2pp.

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16.42.2: Nephrite

Nephrite	
Chemical composition	Complex Ca Mg/Fe (calcium magnesium/iron) silicate
Crystal system	Monoclinic
Habit	Polycrystalline
Fracture	Splintery
Hardness	6.5
Refractive index	±1.62
Specific gravity	2.90 - 3.20
Lustre	Greasy to vitreous

Nephrite has been recognized as a separate type of jade since 1863. It is formed from aggregates of fibrous amphibole crystals. The structure they form is interlocking and tougher than steel. Its colors range from dark green iron-rich varieties to cream colored magnesium rich varieties. It can be found blotchy, banded or singly colored. It's very popular for carving and was used for weapons of the past.

Enhancements

Common enhancements to nephrite:

- Fracture filling - wax - conceal cracks and fractures
- Coatings - wax - to improve luster

Occurrence

Nephrite is found in Turkestan, Myanmar, Siberia (dark green rocks with black spots), Russia, China, New Zealand, Australia (black stones), USA, Canada, Mexico, Brazil, Taiwan, Zimbabwe (dark green), Italy, Poland, Germany and Switzerland. It has been carved by the Chinese for at least 2,000 years.

Sources consulted

- Smithsonian Handbooks, Gemstones, Second Edition 2002

G&G Articles on Jade 1934-1980

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- Fall 1975 **Rare, nearly transparent, light gray faceted jadeite**, p. 73, 2pp.

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16.43: Jeremejevite

Jeremejevite	
Chemical composition	$Al_6B_5O_{15}(F,OH)_3$
Crystal system	Hexagonal or Orthorhombic*
Habit	Prismatic
Cleavage	None
Fracture	Concoidal
Hardness	7
Optic nature	Uniaxial (-) or biaxial*
Refractive index	n_ω=1.653 n_ε=1.640
Birefringence	δ = 0.013
Dispersion	0.0130
Specific gravity	3.27-3.31 (Webster,1994,p.898)
Lustre	Vitreous
Pleochroism	Faint to Strong



Figure 16.43.1***:*** *2.15ct Round faceted, Portuguese-cut Jeremejevite*

Occurrence

Jeremejevite is a rare borate mineral which was discovered in the late 19th Century by a Rusian mineralogist named Pavel Jeremejev.
The known localities for the mineral are:
-Mt.Soktuj, Transbaikal, Russia
-Cape Cross, Swakopmund, Namibia

-The Eifel volcanic area of Germany
-Southwestern Pamirs
-The Fantaziya and Priyatnaya Pegmantite veins of the eastern Pamirs in Tajikistan

Color

Colorless, pale blue, pale blue-green, pale yellow, pale yellowish brown

*Optic Character

The optic character of jeremejevite as been the subject of several contradicting reports.
Webster (1994)describes jeremejevite as an hexagonal crystal with a uniaxial negative optic character in his Identification Tables, however in the text of the same book, he refers to it as an orthorhombic crystal with a biaxial optic character.
Liddicoat (1973) although referring to jeremejevite as uniaxial negative, claimed it has the gem showed evidence of being biaxial with a small 2V angle.
The anomaly was explained by Foord in 1981.
The difference in optic character is a growth phenomenon! The crystal character of the inside of the crystal is different from that of the outside of the crystal. And to further complicate the situation, this difference in optic character, from core to rim, is not consistent. Specimens from one locality can display uniaxial cores with biaxial rims and specimens from another locality can display the opposite character.

Microscopic Observations

Although, atypical of inclusions normally found in jeremejevite, the predominate inclusions found in the Namibian gem featured in the ring above were hollow tubes.

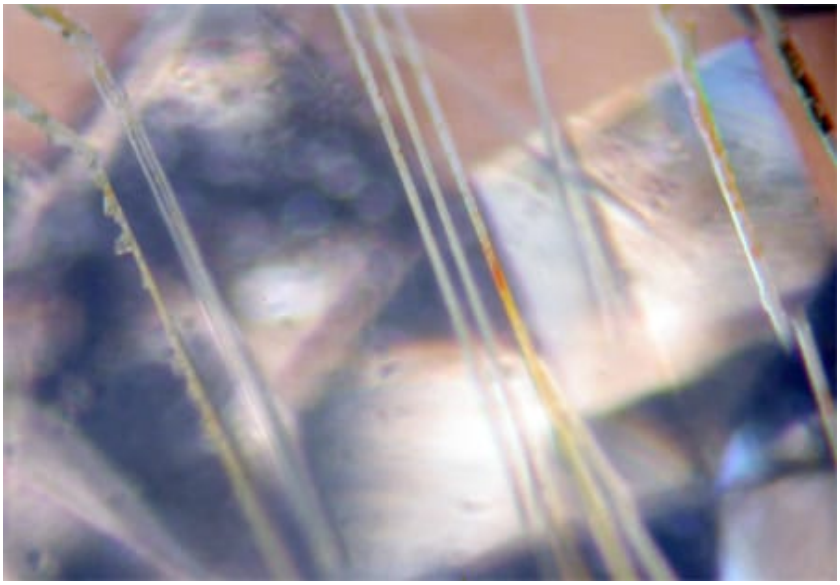


Figure 16.43.2***:*** *Hollow tubes; some filled with a residue; some bearded.*

Additional Information

Jeremejevite. A description of a 400 crystal collection from Namibia
The Jeremejevite reference article by K. Scarratt &al (Gems & Gemology, 2001)
Foord, E.E., Erd, R.C., Hunt, G.R. (1981) New Data for Jeremejevite, Canadian Mineralogist, Vol. 1, p.303-310
Webster, R (1994) Gems, Their Sources, Descriptions and Identification, 5th Edition

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16.44: Kornerupine

Kornerupine	
Chemical composition	Complex borosilicate
Crystal system	Orthorhombic
Habit	Prismatic
Cleavage	Prismatic
Fracture	Conchoidal
Hardness	6.5
Optic nature	Biaxial -
Refractive index	1.67 -1.68
Birefringence	0.013
Dispersion	Low, 0.019
Specific gravity	3.28 - 3.35
Lustre	Vitreous
Pleochroism	Distinct (green, yellow, brown)



Figure 16.44.1***:*** *Faceted Kornerupine*
Photo courtesy of The Gem Trader

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16.45: Kyanite

Kyanite	
Chemical composition	Aluminum Silicate Al_2SiO_5
Crystal system	Triclinic
Habit	Elongated bladed or columnar.
Cleavage	Perfect and good/uneven
Fracture	Uneven
Hardness	4 - 7.5
Optic nature	Biaxial -
Refractive index	1.710- 1.734
Birefringence	0.017
Dispersion	0.020
Specific gravity	3.65 - 3.68
Lustre	Vitreous
Pleochroism	Moderate to Strong, Trichroic

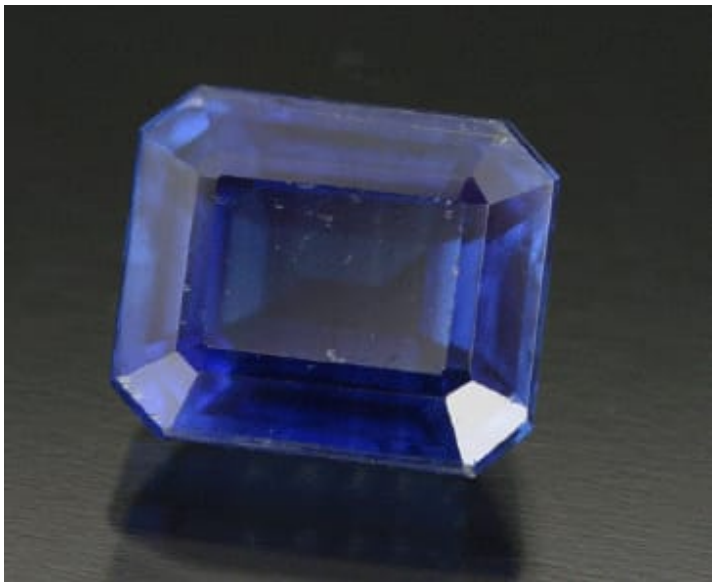


Figure 16.45.1***:*** *Faceted Kyanite*
Photo courtesy of The Gem Trader

Kyanite is an aluminum silicate with the chemical formula Al_2SiO_5. Its name derives from the Greek word "kyanos" which means blue.
The color is blue to colorless, blue-green and brown with a vitreous luster.

Kyanite together with andalusite and sillimanite, all gemstones, belongs to the same polymorphic family. All are isolated tetrahedral silicates and have the same chemical formula but have distinctly different structures.

Kyanite is a metamorphic mineral that occurs in schists, gneisses and granite pegmatites. Associated minerals are quartz,

feldspar, mica, garnet, corundum, and staurolite.

Kyanite occurs as bladed and tabular triclinic crystals. Lamellar twinning is common. It has two cleavage directions, one perfect and the other one good-uneven. It has directional hardness with 4 in the direction of the c-axis and 7.5 in right angles to the c-axis.

Localities: Brazil, Kenya, Mocambique, Norway, Myanmar, Austria, Switzerland etc.

Synonyms: Cyanite, Disthene.

Diagnostics

Kyanite may be confused with:

- Sapphire
- Spinel
- Tanzanite
- Idocrase

Diaphaneity

Transparent to translucent.

Color

Kyanite is allochromatic and occurs in the colors blue to colorless, blue-green, brown and orange.
The blue variety is the most used as a gemstone.

The cause of color is iron and titanium for blue stones (charge transfer from Fe^{2+} --> Ti^{4+}) and vanadium for green ones. Orange stones are probably colored by iron and/or manganese.

Hardness

Kyanite has directional hardness with 4 to 5.5 in the direction of the c-axis and 7 to 7.5 at right angles to the c-axis.

Cleavage

Kyantite has perfect cleavage along one prism direction {100} and good cleavage along the {010} plane. It also has basal parting {001}.

Streak

White.

Refractometer

n_α = 1.710 - 1.718, n_β = 1.719 - 1.724, n_γ = 1.724 - 1.734 with a birefringence of 0.012 to 0.017.
Optical nature: biaxial negative.

Pleochroism

Moderate to strong (weak in orange stones).
Blue stones: colorless, blue, dark blue.

Luminescence

LW-UV: weak red.

Spectroscope

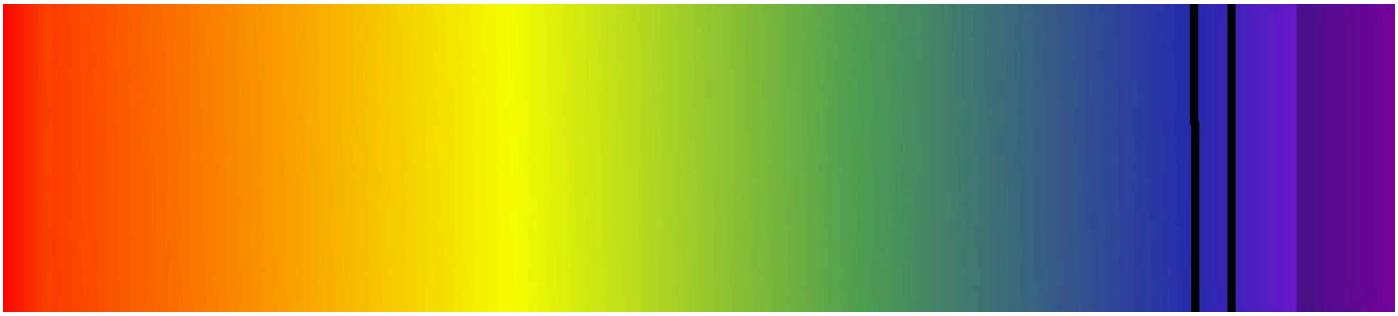


Figure 16.45.2***:*** *Spectrum of green and some blue kyanite*

Blue kyanite may show two lines in the blue with a general cut-off in the violet. Other lines in the red and deep red may be seen in bluish green kyanite.
Absorption lines: (706), (689), (671), (652), 445, 435.

Notice that the image resembles the "450 complex" of iron-rich sapphire. In this image, the 445 and 435 nm lines are shown as well as the cut-off in the violet.

For orange stones, there can be a line at 553 and a general absorption in the blue-green/blue.

Specific Gravity

Kyanite can have a specific gravity from 3.53 to 3.68, but for gem material it is usually in the higher 3.67 region. It sinks in all common heavy liquids.

Magnification

- Strong color-zoning
- Parallel needles
- Liquid feathers

Durability

Due to its perfect to good cleavage along the {100} and {010} prism planes, the stone should be protected from being knocked in the direction of the prism faces. It also shows good parting along the basal {001} plane.
In addition, the relative hardness of 4-5.5 in the direction of the prism faces makes it an even less candidate to be set in jewelry pieces that are prone to abrasion, as rings.

Phenomena

Chatoyancy is reported, but rare.

Sources

- Gems Their Sources, Descriptions and Identification *4th Edition (1990) - Robert Webster (6th ed.)*
- *Gemstones of the world, 3rd Rev Exp edition* (2006) - Walter Schuman ISBN 1402740166

- *Mineralogy second edition* (2002) - Dexter Perkins ISBN 0130620998
- *Gem Reference Guide* (1995) - GIA ISBN 0873110196
- *FlashData #25: Kyanite orange Tanzanie* - *J.-M. Arlabosse, 2008*

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16.46: Lapis Lazuli

Lapis Lazuli	
Chemical composition	rock consisting of lazurite, hauyne, calcite and pyrite
Habit	aggregate
Fracture	uneven
Hardness	5.5
Refractive index	1.500 - 1.670
Specific gravity	2.50 - 3.00
Lustre	resinous to vitreous

Figure 16.46.1***:*** *Lapis Lazuli with Pyrite inclusions*

Enhancements

Common enhancements to lapis lazuli:

- Fracture filling - wax (with dye or without) - conceal cracks and fractures and to improve luster
- Dye - color staining - to produce evenly colored material

Images



Figure 16.46.2***:*** *Untreated lapis lazuli cabochon from Afghanistan. Image courtesy of Scott Davies.*

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16.47: Larimar

Larimar	
Chemical composition	$NaCa_2Si_3O_8(OH)$
Crystal system	Triclinic
Habit	Aggregate
Hardness	5
Optic nature	Biaxial +
Refractive index	1.59 - 1.63
Birefringence	0.028-0.038
Dispersion	Very weak
Specific gravity	2.62 - 2.87
Lustre	Silky
Fluorescence	Yellow or orange (SW-UV)

A blue pectolite found in the Dominican Republic. See pectolite

Acknowledgments and External Links

Gems & Gemology, Winter 1989 Issue Larimar
Blue Pectolite from the Caribbean

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16.48: Malachite

Malachite	
Chemical composition	$Cu_2(CO_3)(OH)_2$
Colors	Banded light and dark green
Crystal system	Monoclinic
Habit	Botryoidal, stalactitic, globular
Cleavage	Distinct
Fracture	Conchoidal, splintery
Hardness	3.5-4
Optic nature	Biaxial -
Refractive index	1.655 - 1.909
Birefringence	0.254
Dispersion	Weak
Specific gravity	3.60 - 4.05
Lustre	Dull, silky, vitreous
Transparency	Translucent to opaque
Pleochroism	None
Sources	Australia, Namibia, Russia, USA, Zambia, Zaire

Sources

- *Gemstones - Properties, identification and use* (2008) - Arthur Thomas ISBN 9781845376024

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16.49: Maw-sit-sit

Maw-sit-sit	
Chemical composition	Chromium bearing rock
Hardness	6-7
Fracture	Irregular to conchoidal
Refractive index	1.52 (common) - 1.74
Specific gravity	2.5-3.5
Lustre	Vitreous to oily



Figure 16.49.1***:*** *Cabochons of Maw Sit Sit*

Maw-sit-sit image gallery

Maw-sit-sit is a chromium-rich metamorphic rock with brilliant emerald green blotches and bands interspersed with dark green-black blotches. It is found in Tawmaw, Myitkyina-Mogaung District, Kachin State, Myanmar.
It was first noted in the early 1960's by the famed Swiss gemologist Eduard J. Gübelin during field investigations in Burma. The locality is near the historic imperial jadeite mines of northern Myanmar.

Synonyms: mawsitsit, maw-sit-sit jade, chrome-jade, kosmochlore-jade, chrome-albite, jade-albite, chloromelanite.

Chemical composition

Most of the component minerals of mawsitsit contain chromium as either an essential element or as an impurity. The proportions of each component mineral can vary from example to example.

- Kosmochlor – the dominant mineral species in mawsitsit is kosmochlor, a sodium chromium pyroxene previously called "ureyite". (Ureyite was discredited as a mineral species when it was determined to be identical to kosmochlor.) Kosmochlor constitutes about 60 percent of mawsitsit, and is the primary component of both the brilliant emerald green and dark green-black patches.
- Chromian Jadeite – a chromium-enriched jadeite makes up approximately 15 percent of mawsitsit.
- Chromian Eckermannite – a chromium-enriched sodium, magnesium, iron amphibole group mineral, makes a small contribution of only about 4 percent of mawsitsit.
- Chromian Albite – a chromium-enriched albite usual constitutes 1 per cent of mawsitsit.
- "Symplectite" – On several occasions, derivative descriptions of the mineralogy of mawsitsit includes "symplektite" (symplectite) in the list of the mineral species present. Symplectite is not a mineral but rather a petrographic texture, a microscopically-fine intergrowth of two or more minerals resulting from high-pressure metamorphism.
- Minor and trace minerals include chromite (usually as opaque, microscopic relict grains), natrolite, an imprecisely identified

chlorite-group mineral and an imprecisely identified serpentine-group mineral.

Diagnostics

Color

Brilliant emerald green to dark green, almost black. Patterning varies from splotches to swirls to veins and bands.

Diaphaneity

Opaque; very slightly translucent in thin splinters.

Refractive Index

The refractive index has been given as varying between 1.52 (most common) and 1.74. The refractive indices for the two dominant minerals present in maw-sit-sit are:

- Kosmochlor: biaxial, n_α = 1.766, n_γ = 1.781, birefringence = 0.0150
- Jadeite: biaxial (+), n_α = 1.654-1.673, n_β = 1.659-1.679, n_γ = 1.667-1.693, birefringence = 0.0130-0.0200

Occurrence

Maw-sit-sit was the result of high pressure, low temperature metamorphism of a chromium-rich ultramafic rock. It occurs on the rim of a peridotite intrusion that has been altered to serpentine. To date, the occurrence in northern Myanmar appears to be unique. A mixture of kosmochlore with eckermannite has been noted in Japan, but bears no resemblance to mawsitsit.

Care

It has been suggested that maw-sit-sit not be cleaned using ultrasonic cleaners or chemical cleaning agents, nor should it be exposed to rapid fluctuations in temperature.

Sources

- Hänni, H.A. & Meyer, J. (1984): Is there a gap in the solid solution between jadeite and Ureyite? (German original title: Besteht eine Mischungslücke in der Reihe Jadeit-Ureyit). Paper verbally presented at Bern-Basel Colloquium in Bern.
- Chiu Mei Ou Yang. 1984. A terrestrial source of ureyite. American Mineralogist, Vol. 69, pp 1180-1183
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- Htein, W. and A.M. Naing. 1995. Studies on kosmochlor, jadeite and associated minerals in jade of Myanmar. Journal of Gemmology. Vol. 24, pp.315-320
- Qi, L., X. Lu, W. Liu and Q.Ouyang. 2003. Maw-sit-sit jade from Burma: A particular jade formed by dynamic metamorphism and metasomatism. Journal of Gems and Gemmology. Vol. 5 No. 4, pp.1-7

Additional notes

Prof. Hänni added the following to the sources entry:

"I would like to add an early reference on Maw-sit-sit analysis, the data were presented verbally in Bern in Spring 1984. The research was done on thin sections, using optical and microprobe methods. The in those days new and striking results were presented at a colloquium hold every year between the mineralogical institutes of Basel and Bern, Switzerland. Hänni and Meyer have already gone a long way to finish a publication when the paper of Ou Yang appeared in later 1984. There was all power lost to finish and publish almost the same as the findings of Ou Yang showed. Hänni came back to the topic in an International Gemmological Conference IGC in Idar Oberstein 1997 much to the amusement of Ms Ou Yang, who was in the audience."
[ed.: source now mentioned]

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16.50: Opal

Opal	
Chemical composition	SiO_2+.H_2O
Crystal system	Amorphous
Hardness	5- 6 1/2
Refractive index	1.45 (+.020;-0.080)
Specific gravity	2.15 (+0.07;-0.90)
Lustre	Vitreous
Phenomenom	Play of Color

Diagnostics

Description

Opal is a mineral species with an amorphous structure. Its composition is silicon dioxide with a variable amount of water. The amount of water (H_2O) is usually between 2-10% by weight, although contents as high as 20% have been recorded. When opals undergo dehydration as a result of exposure and time they have a tendency to become crazed, showing minute cracks on the polished surfaces.

In 2000, The Australian Gemstone Industry Council established nomenclature and classification standards for all types and origins of opals, This classification has been adopted internationally.
Opals can be broken down into 2 basic categories:

- ***Precious Opal:*** any opal displaying play-of-color. This phenomenon is caused by the diffraction of white light thru a microscopic, orderly arrangement of silica spheres. This category includes white, black and boulder opal. Precious opal can be further distinguished by types:



Figure 16.50.1***:*** *Mintabe Opal Rub*
Photo courtesy of Kevin Schwebel, Handmade Enterprises

Type 1: A single, solid piece of precious opal, having a uniform appearance and composition. This is the type of opal most commonly used for jewelry
Type 2: Precious opal that is attached to its host rock (a non-opal) in the form of a layer or seam. Boulder opal is an example of

this. The opal is attached to a brown, iron-stained sandstone.
Type 3: Matrix opal occurs when precious opal fills cracks and openings in the host rock. The opal forms in pre-existing clay or sandstone. This material is frequently dyed.
Doublets & Triplets: These assembled stones are not considered natural opals, although they do contain a layer of natural opal.

- ***Common Opal or Potch***: These are varieties of opal that do not show a play-of-color. Although they share the same chemical composition as precious opal, the silica spheres they contain are randomly arranged.



Figure 16.50.2***:*** *Yellow Common Opal*
Photo courtesy of Rick Martin, Art Cut Gems

Color

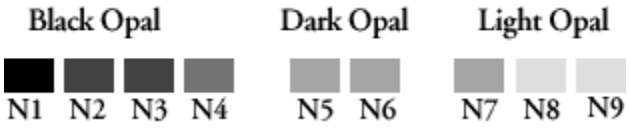


Figure 16.50.3

Judge the body color of an opal "face up".
Example:
If an opal has very dark potch on the back, giving it the appearance of N5, it should be graded as N5.

Transparency



Figure 16.50.4***:*** *Precious Mexican Crystal Opal Photo courtesy of Rick Martin, Art Cut Gems*

Opals can vary in degrees of transparency from transparent to opaque. When an opal is transparent or semi-transparent it is referred to as "crystal". This is true regardless of the body tone. "Crystal" refers to the glass-like appearance of the gem, NOT a crystalline structure.

UV Reactions

Black opal is usually inert, but light varieties of opal, both common and precious may fluoresce in both LW and SW ultraviolet light. Some natural opals phosphoresce green after exposure to LW ultraviolet light. Synthetic opals do not.

Chelsea Colour Filter

No diagnostic reaction.

Treatments



Figure 16.50.5***:*** *Opal treated with carbonized sugar and acid*

- Treatment with aniline dye, silver nitrate, or sugar carbonized with acid.
- Impregnation with oil, wax, or plastic.
- Smoke impregnation.
- Impregnation with black plastic.
- Backing with foil, black paint, or laquer.

Phenomena

Play-of-Color.

Synthetics

The firms of Gilson in France and Chatham in the United States currently create synthetic opals. They are produced with white and black body colors. Chatham also markets a "crystal" type which exhibits a colorless body with play of color.
This laboratory-created material was first marketed by Pierre Gilson, Sr. in 1974. It involves a 3 stage process involving the purification of chemicals involving fractional distillation. This is characteristically an elaborate process involving the consolidation of these refined chemicals under water pressure. The result is the creation of microscopic cristobalite silica spheres (SiO_2) of uniform size. They are allowed to settle in the containment vessel for over a year in a hydrous solution of controlled pressure and acidity. Then, a hydrostatic press is utilized to consolidate the microspheres from a liquid phase into a solid phase, resulting in synthetic opal rough which can be cut into cabochons.

Imitations

Slocum Stone: Glass Imitation (separation: magnification, RI, SG)
Japanese Plastic with Play of Color (separation: SG, Hardness: pressure with a pin will make a slight indentation)

G&G Articles on Opal 1934-1980

The GIA has published all the G&G's from 1934 until 1980 online. The organization of the list by subject was done by Joseph Gill.

- Winter 1937, **The Australian Black Opal**, p. 137, 2pp.
- Winter 1938, **Opal (with glossary of varieties)**, by Briggs, p. 201, 2pp.
- Winter 1946, **New Australian Opal Fields**, p. 364, 3pp.
- Fall 1947, **Mexican Treated Black Opal**, p. 475, 2pp.
- Fall 1950, **Opal Industry of Australia, past and present**, p. 334, 8pp.
- Winter 1950, **British Collector Now Owns the Pandora Opal**, p. 381, 1p.
- Spring 1953, **Mexican Opal**, by Foshag, p. 278, 5pp.
- Fall 1959, **Opal of Australia**, p. 323, 11pp.
- Winter 1965, **The Black Opals of Lightning Ridge**, p. 355, 4pp.
- Fall 1971, **The Story of the White Cliffs Opal Field, Australia**, p. 334, 10pp
- Fall 1971, **A carved 288.25 ct**. Mexican opal, p. 357, 2pp.
- Fall 1972, **Opal with play-of-colors found in Arizona**, p. 91, 1p.
- Fall 1976, **Opalescent Sandstone from Louisiana**, p. 201, 1p.
- Fall 1979, **COOBER PEDY - The Opal Town**, by J. Stone, p. 213, 4pp.
- Spring 1980, **GEMLURE, Opal: Smolder of Fortune?,** by Cheri Lesh, p. 283, 6pp.
- Nov.-Dec. 1935, **New type of opal doublet**, p. 344, 1p.
- Fall 1948, **Variation in opal properties per locality**, p. 90, 2pp.
- Winter 1953, **Cause of Color in Opal**, by Leechman, p. 361, 4pp.
- Spring 1954, **The Structure and Optical Behavior of Iridescent Opal**, p. 21, 6pp.
- Spring 1955, **Lattice Structure in Precious Opal**, by Leechman, p. 154, 2pp.
- Fall 1959, **Treated black opal**, p. 343, 1p.
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- Fall 1964, **Opal triplet; black onyx backed, quartz topped**, p. 221, 2pp.
- Winter 1964, **Treated black opal and its patchy iridescence**, p. 242, 2pp.
- Summer 1965, **The Origin of Color in Opal**, p. 291, 8pp.
- Summer 1966, **A cat's-eye opal**, p. 60, 2pp.
- Spring 1967, **Oolitic opal**, p. 149, 2pp.
- Summer 1967, **An opal that loses its color when water soaked**, p. 179, 2pp.
- Fall 1967, **Formation of Precious Opal**, p. 194, 5pp.
- Fall 1967, **Oolitic opal**, p. 199, 1p.
- Fall 1967, **Opal substitutes (crushed opal in resin)**, p. 219, 3pp.
- Spring 1968, **Opal and rock crystal doublets**, p. 282, 2pp.
- Fall 1968, **Rare cat's-eye opals**, p. 342, 2pp.
- Winter 1968, **Odd leaf-like inclusion in an opal**, p. 380, 2pp
- Spring 1969, **Opal imitation**, p. 21, 1p.

- Spring 1969, **Some unusual opal inclusions**, p. 26, 3pp
- Summer 1969, **Chrysocolla opal (first seen)**, p. 67, 2pp.
- Fall 1969, **Smoke-treated opal**, p. 91, 2pp.
- Fall 1969, **Some unusual opals**, p. 97, 2pp.
- Winter 1969, **Artificially colored opals**, p. 117, 1p.
- Winter 1969, **An unusual sugar-and-acid-treated opal**, p. 127, 1p.
- Spring 1970, **A porous white opal impregnated with black plastic**, p. 148, 1p.
- Winter 1970, **Stained black opal**, p. 249, 3pp.
- Spring 1971, **Nomenclature of black opal**, p. 284, 2pp
- Summer 1971, **A new opal, treated black, with very low properties**, p. 317, 2pp.
- Summer 1971, **A very unusual opal**, p. 321, 2pp.
- Fall 1971, **Black-dyed oolitic opal**, p. 351, 2pp.
- Winter 1971, **Natural black oolitic opal**, p. 382, 1p.
- Spring 1972, **New synthetic opal from Gilson**, p. 18, 1p.
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- Spring 1972, **Easily testing a mounted opal doublet**, p. 24, 3pp.
- Summer 1972, **An opal cabochon in which the chipped back was epoxy filled**, p. 43, 2pp.
- Fall 1972, **High transparency in some black opals**, p. 88, 2pp.
- Winter 1972, **Sugar-treated black opal, demonstration**, p. 117, 1p.
- Summer 1973, **Gilson synthetic opal**, p. 175, 3pp.
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- Fall 1974, **Imitation opal on matrix**, p. 331, 2pp.
- Fall 1974, **Gilson synthetic opal (black)**, p. 343, 1p.
- Winter 1974, **An excellent opal imitation**, p. 362, 3pp.
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- Summer 1976, **Crystal inclusions in Mexican opal**, p. 174, 1p.
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- Fall 1976, **Non-Single-Crystal Synthetic (synthetic Gilson opal)**, by Nassau, p. 194, 5pp.
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- Winter 1976, **Opal doublet to imitate boulder opal**, p. 115, 2pp.
- Winter 1976, **Gilson synthetic opal**, p. 126, 1p.
- Winter 1977, **Gilson black opal triplet**, p. 236, 1p.
- Winter 1977, **Observations on the Slocum Stone**, p. 252, 5pp. (See also Summer 1977, p. 301, 1p. and p. 308, 1p.)
- Summer 1978, **Plastic Impregnated Gem Opal**, by D. Vincent Manson, p. 49, 9p.
- Fall 1979, **Plastic Impregnated Opal and Plastic Opal**, p. 219, 1p.

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- Secrets of the Gem Trade, by Richard W. Wise
- *A Student's Guide to Spectroscopy* (2003) - Colin H. Winter
- *Gem Identification Made Easy* 3rd edition (2006) - A.C. Bonanno/ Antoinette Matlins
- *GIA Gem Reference Guide* for the GIA Colored Stone & Gem Identification Courses

External Links

- Opal Nomenclature and Classification

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16.50.01: Black Opal

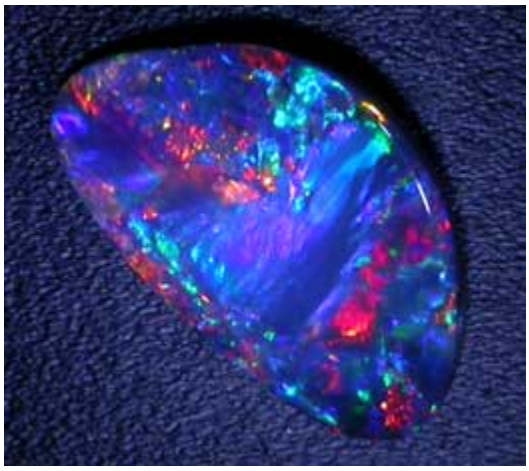


Figure 16.50.1.1***:*** *Lightning Ridge Black Opal, 3.90 ct*
Photo by Jeff Scovil
Courtesy of R.W. Wise Goldsmiths

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16.50.02: Blue Peruvian Opal

Opal	
Chemical composition	SiO_2+.H_2O
Crystal system	Amorphous
Hardness	5- 6 1/2
Refractive index	1.45 (+.020;-0.080)
Specific gravity	2.15 (+0.07;-0.90)
Lustre	Vitreous
Phenomenon	Play of Color

The name comes from the source from where it is mined, the Peruvian Andes.
Other tradenames include Andean opal, Andean blue opal, Andean blue silica, and blue opal.

Diagnostics

Color

Aquamarine to sea-green color due to trace amounts of copper.

Occurrence

Main source: San Patricio, Peru.

Care

Opal is relatively soft, Peruvian opal should be treated with care as it can be scratched by any harder material. Wash in warm soapy (non-detergent) water.

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16.50.03: Boulder Opal

Boulder Opal is a unique and beautiful opal found in Queensland, Australia. It is easily identifiable because it is a mixture of ironstone and opal either in a matrix or layered. Every stone is unique and they are arguably the most affordable opal available.

This unique opal is spread over thousands of miles and known as the Winton Formation, which is millions of years old. Famous Boulder opal fields include Winton, Quilpie, Opal town, Jundah, Bulgarro, and Kyabra.

Koroit and Yowah are two opal fields close together and are now producing popular opal that has more pattern and unique style more than color as most boulder opal fields.

We have now added these fields under Boulder opal as many new buyers miss these categories. They have a reputation for veins of color in spectacular patterns compared to other Boulder opals fields

Koroit and Yowah generally have more dark chocolate ironstone backing and other opals fields have more sandstone light brown color and both can display veins caramel color.

Boulder opals have more variety and uniqueness compared to other opals and gemstones as so many factors have taken place over million years and different mineralization has helped in the huge cross spectrum of unique boulder opals that you can enjoy

Another interesting type of Boulder Opal is the wood replacement fossil. These stones have replaced a cavity left over by old wood. This creates a stone with a unique wood pattern. Check them out, they are amazing.

Please note some color bars on this opal is very thin and sometimes buyers mistake for doublet which is man-made by joining crystal opal to ironstone.

To check that it is genuine opal, best to have a magnifying glass and view color bar and you can see it isn’t glued by following color veins. Also, you may place it in the freezer for a few minutes and if it's a doublet, the glue would crystallize and become easy to see.

It is an extremely stable type of opal that does not generally crack or craze. Since it is mixed with ironstone it is very strong and resistant to breaking, but some boulder opals do show crack lines and most of these are caused when the opal was formed as many times you will split open a boulder opal to see crack lines which could have been caused by shifts in the earth to earthquakes or movements when the opal was forming.

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16.50.04: Fire Opal



Figure 16.50.4.1***:*** *Fire opal*

Fire Opal image gallery

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16.50.05: Pink Opal

There may also be color striation as real opal will have color striation or unevenness of color due to the coloring. In the case of pink opal, it is colored by clay that surrounds it or it is usually found in, a mineral called palygorskite. Pink Opal has a hardness of 6; making the pink opal some of the hardest opal in the world. Some pink opal also comes from Mexico and some other places in the world. Some of the very top material is saturated with color actually making it reddish. These are rare pieces, There also has been a little drusy a coating of fine crystals on a rock fracture surface, vein or within a geode found in the pink opal but mainly for collectors and in small areas. The Pink Opal is high in silica in which this opal is almost a pink chalcedony but it is opal and has opal cleavage. There is never a water problem with pink opal and it is stabile.

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16.51: Pearl

Pearl	
Chemical composition	Calcium carbonate, conchiolin and water
Crystal system	Amorphous
Hardness	2.5-3.5
Refractive index	1.52-1.69
Specific gravity	2.68-2.86
Lustre	Pearly



Figure 16.51.1***:*** *The Baroda Pearls*
Photo courtesy of Christie's Images LTD. 2007

The most famous pearl necklace is the 2 strand Baroda pearl necklace (known as "The Baroda Pearls"). It is made of 68 graduated (9.47 to 16.04 mm) natural pearls, all matched to color, luster, size, and shape. It is assembled from the original 7 stranded pearl necklace owned by the Indian Maharajas of Baroda.
The Baroda pearls were sold in auction at Christie's New York for USD 7,096,000 an all-time auction record (April 25th, 2007).

Formation

Pearls are, usually, created by certain types of mollusks, which we shall refer to as oysters or pearl oysters, when an inorganic or organic material is embedded between the mantle and the inner shell of the oyster.

The mollusk group is a large group of (mostly marine) animals, such as oysters, clams, mussels, and marine snails. Land snails, slugs and squids also belong to this group. In gemology mostly the marine univalve and bivalve animals that have decorative shells or are able to create commercially viable pearls are important. Cuttlebone from cuttlefish (also a mollusk) is used as a casting medium in jewelry.

The mantle is the outer organ of the oyster which covers most of the shell. The outer cells of this mantle (called the *epithelium*) are responsible for the secretion of nacre and conchiolin (AKA mother-of-pearl).



Figure 16.51.2***:*** *Mother of pearl with drill holes caused by living organisms*
Photo courtesy of Parels-AEL

Natural pearl formation is very rare and usually happens when a parasite or other living organism drills its way through the shell of the oyster, where it will then encounter the mantle. The mantle is irritated by this parasite and tries to defend itself by encapsulating the irritant with epithelial cells, forming a sac of cells covering this parasite. These cells will then secrete layers of nacre and conchiolin on the parasite.
Conchiolin is an organic substance made by the epithelial cells that act as a glue between different layers of nacre (a calcium carbonate).

Mostly this process takes place in the mantle of the oyster and free pearls of all shapes are formed. When an irritant is attached to the inner shell, then epithelial cells will deposit conchiolin and nacre on the irritant and it will form a *blister* on the inside of the oysters' shell. To no surprise, the latter type of pearls are named *blister pearls*.

There are other irritants that may induce pearl formation, but the story that they originate from sand grains is a myth. Although it could be possible that a grain of sand gets trapped between the mantle and the shell, it is very unlikely. Oysters live in sandy environments and they simply "spit" any dirt out.

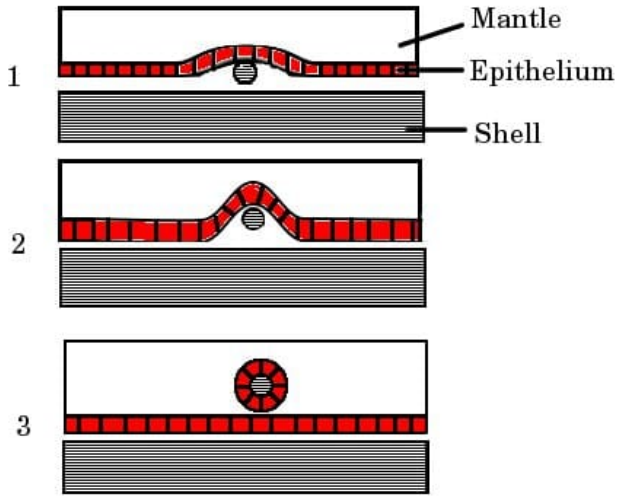


Figure 16.51.3***:*** *Formation of natural pearls*

In the image above the formation of a natural pearl is illustrated.

1. An irritant is trapped between the mantle and the inner shell of the oyster.

2. The epithelial cells start to divide and try to encapsulate the irritant.

3. The irritant is now fully enclosed with epithelial cells and has moved inside the mantle. This creates a sac of

epithelial cells around the irritant. Such a sac is named a *pearl sac*.

From the outside in, the pearl sac (the cells) secrete nacre and conchiolin unto the irritant and the pearl starts to grow. The pearl sac expands through cell division as the pearl grows.

In this illustration, a "free" pearl is formed. When the irritant attaches itself to the shell, then there will be no formation of a pearl sac and the epithelium cells just deposit nacre and conchiolin on the irritant and the inner shell, creating a blister.

A pearl sac is essential in the formation of free pearls, for both natural as cultured pearls.

Types of oysters



Figure 16.51.4***:*** *Inside of a Pinctada margaritifera shell*
Photo courtesy of Parels-AEL

There are many oysters (bivalve mollusks) that can form pearls, either living in fresh or saltwater. The species that produce pearls of commercial value are listed below.

- Pinctada martensii (Akoya pearls)
- Pinctada maxima (South Sea pearls)
- Pinctada margaritifera (Black or Tahiti pearls)
- Pteria sterna (Sea of Cortez pearls®)
- Pinctada mazatlanica (Mexican pearls)
- Pteria penguin (Blister pearls - Mabe)
- Haliotidae haliotis (Abalone)

- Hyriopsis cumingi (freshwater "Zebra mussel")
- Cristaria plicata (freshwater "Cockscomb mussel")

There are also other mollusks (gastropods) that can produce pearls without nacre. Some people do not regard these as real pearls (due to the lack of nacre), but the formation is strongly related to that of oysters and the "pearls" they produce are very rare.

- Strombus gigas (Conch pearls), a marine snail
- Melo melo pearls, a marine snail
- Mercenaria mercenaria (Quahog or "Hard clam")

When the pearl formation is natural without any intervenience by man, we name them natural or "oriental" pearls. Otherwise, we refer to them as "cultured" pearls.

Cultivation

Since the middle ages, people have been trying to influence the creation of pearls by oysters and mussels. This is named "cultivation" and the pearls that are created in such a way (with some influence by man) are termed "cultured pearls". Often, but not always, the entire product is of natural origin (from mollusks) and by law are considered as natural pearls.
Pearls that grow without any intervenience by men are sometimes named "oriental pearls".

Early cultivation

Although most cultured pearls on today's market are created entirely by mollusks, that was not always the case. In the 13th century [Webster, 1990] the Chinese made blister pearls in the form of Buddha statues by placing a metal Buddha against the inner shell of a freshwater mussel and keeping it in place with a metal wire that was connected through an artificial drill hole. Some sources indicate that this has even been done as early as 1082 [Huang et al, 2003].

Carl von Linné (better known as Linnaeus) was able to create the first free cultured pearls in 1761, but the final product was not in total created from mollusks. He drilled a hole in a freshwater mussel and inserted a silver wire with a piece of limestone into the mussel, making sure the limestone was free from the inner shell to prevent it from becoming a blister pearl. While he was the first to create some sort of free pearl, the results were not as good as the cultured pearls that are created today.

Modern cultivation

In the late 19th and early 20th century, several people were independently researching how to cultivate better round pearls.
One of the most agile and best known of these entrepreneurs was Japanese Kokichi Mikimoto (1858-1954) who was able to create cultured blister pearls in 1893 and was granted a patent for it 2 years later.
Around the same time William Saville-Kent (1842-1908), an English scientist, conducted parallel research on Thursday Island (Torres Strait, Queensland, Australia). Saville-Kent gave evidence of his cultured blister pearls in 1891, 2 years earlier than Mikimoto did [Harrison, 2005].
Both Mikimoto and Saville-Kent were from there on in search of a method to create detached cultured pearls.

The Mise-Nishikawa controversy

In 1907 Japanese Tatsuhei Mise and Tokichi Nishikawa both applied for a patent to create such detached pearls and the method they used is known as the "Mise-Nishikawa method". This method is still used today.

While it took Mikimoto decades of research to create his first detached cultured pearls in 1908, Mise and Nishikawa patented a better method independently of each other in 1907 with none to little research.
Mise was a carpenter with no training in pearl cultivation and Nishikawa a young graduate from the university of Tokyo. In 1901 Nishikawa and Mise's stepfather (a senior inspector for the Japanese bureau of fisheries) were sent to Thursday Island to inspect the Japanese fleet. It is known that around this time Saville-Kent was experimenting with mantle tissue and nuclei to create round cultured pearls with some success. On the islands in the Torres Strait some 2000 Japanese were involved in the pearl and fishery industry and it is very plausible that Nishikawa and Mise's stepfather had been informed about Saville-Kent's work at Thursday Island. As both Mise and Nishikawa had almost instant success in their efforts to create round cultured pearls instead of doing decades of research, one can only wonder if they indeed were the inventors of their method [Harrison, 2005].

The Mise-Nishikawa method involved a small starting bead (of metal or other material) and some mantle tissue that were placed in the gonad (the reproductive system) of the pearl oyster.

Mikimoto himself was trying to create round pearls in the mantle of the pearl (where natural formation takes place), but his method (which involved silk threads to keep a sack around the starter bead) was not very successful.
He, however, perfected the Mise-Nishikawa method and was responsible for the more than successful marketing of cultured pearls. Due to his never-ending diligence, cultured pearls are now the norm when we speak of pearls. There is hardly any trade in natural pearls today.

The Mise-Nishikawa method

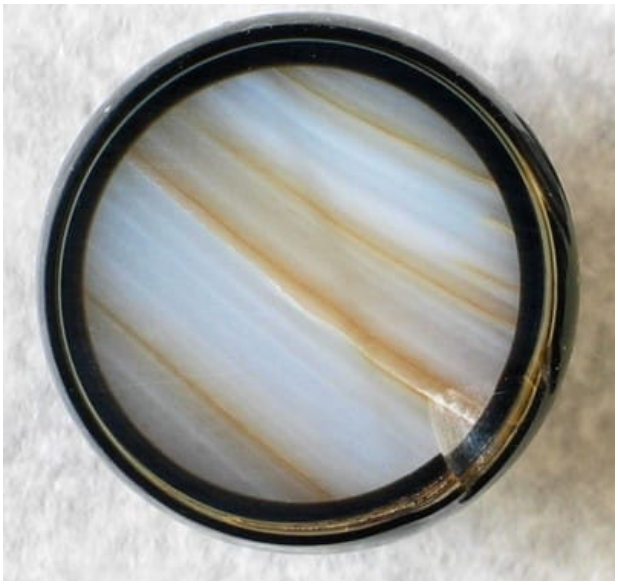


Figure \({16{.}51{.}\eatSpaces{5} \endSpaces}\): *Cross section of a cultured Tahiti pearl, showing the freshwater nucleus and the natural dark nacre*
Photo courtesy of Parels-AEL

This method is the primary method to create round cultured natural saltwater pearls. It involves a starter bead made from the thick shells of North-American freshwater mussel shells (such as the pig-toe shell, the three-ridge shell, and the washboard shell) and a small tissue of mantle from a donor oyster.

The shells are harvested mainly in the Mississippi and Tennessee rivers. They are sawn into squares and then rounded into spherical beads with a high polish to form a starter bead for saltwater pearl cultivation.
It was Mikimoto who found that starter beads from these shells were best to serve as a "nucleus" for saltwater cultured pearls. We shall refer to the starter beads as nuclei from now on.

As pearls can not grow without a pearl sac, a piece of mantle tissue is taken from a donor oyster and cut in small pieces (2-3 mm).

Young pearl oysters are carefully selected to be implanted with both a nucleus and a small piece of mantle tissue. With high precision, an incision is made in the flesh of the oyster to gain access to the gonad and the selected mantle tissue is inserted into the gonad. Then the freshwater nucleus is placed into position in the gonad. It takes great skill to place the nucleus and the mantle tissue so that a pearl sac can be formed from the mantle tissue around the nucleus.
The size and amount of nuclei that can be implanted depends much on the size and species of the oyster.

This all has to be done very rapidly and after the surgery the oysters are placed in special nets which are returned to the sea for a certain amount of time (usually a few years).

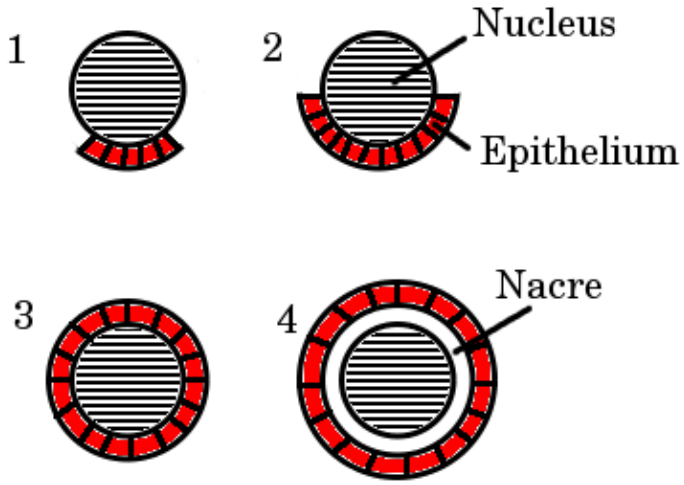


Figure 16.51.6***:*** *Formation of the pearl sac and pearl inside the gonad*

The mantle tissue will start to divide its epithelial cells and forms a pearl sac around the nucleus. This sack will then start to deposit conchiolin and nacre onto the nucleus and the pearls will start to grow in concentric rings around that nucleus.

The stages of nucleated cultured pearl formation:

1. The mantle tissue and the nucleus are inserted into the reproductive system of the pearl oyster
2. The epithelial cells of the grafted mantle tissue start to divide
3. The pearl sac is formed
4. The epithelial cells secrete nacre (and conchiolin) onto the nucleus in concentric rings and the pearl grows

Non-nucleated cultivation



Figure 16.51.7***:*** *A freshwater pearl string (9-9.5 mm) in a plethora of colors*
Photo courtesy of Parels-AEL

While the Mise-Nishikawa method involves both a nucleus and a piece of grafted mantle tissue, one can also induce pearl

formation without a nucleus. Thus with a grafted piece of mantle tissue alone. This method is used primarily for freshwater pearls.

A small piece of donor tissue is implanted ("grafted") in the mantle of the selected freshwater mussel and this tissue takes nutrition from the mantle in which it is grafted. While the donor tissue grows through cell division it is becoming more and more difficult to get nutrition to the inner epithelial cells and these cells start to decay, forming a cyst with the decayed cell fluids. Epithelial cells that line this cyst now start to secrete layers of conchiolin and nacre and the pearl starts to grow in concentric rings. Up to 40 implantations can be done in a single parent mussel.

The result is a freshwater pearl that is composed of 100% nacre and conchiolin produced by the same mussel, as opposed to the nucleated saltwater pearls. In many of these pearls, one will find a small void in the center; this is believed to originate from the cyst formation.

In China (where most of this production takes place) they are now able to create large round pearls (up to 15mm) in almost any color, except black. Some of the white freshwater pearls can rival the best of the saltwater Akoya pearls these days [Huang et al, 2003].

It is estimated that these Chinese freshwater pearls make up 90% of the whole cultured pearl production (including saltwater pearls).

Although somewhat round nucleated freshwater pearls were created in Japan (Kasumiga pearls) at some time (and even in the 18th century by Linnaeus), that technique is still not yet perfected in China. It is expected that they will have solved that problem in the foreseeable future.
One can get nucleated freshwater pearls, but not perfectly round ones.

Harvesting

After a certain amount of time, the mollusks are taken from the sea, or lake, for the harvesting of pearls.
Depending on whether the mollusk is suitable for another session of cultivation, the mollusks are either broken or are operated to collect the pearls (and in some cases the meat). In the first case, the mollusk dies.

After the harvesting of the pearls, they are then cleaned and send to the grading facilities where they are sorted on their physical appearance, like lustre, shape, color, size, and blemishes.
Sometimes the harvested pearls undergo a bleaching or staining process to enhance the color.

Grading

Unlike with diamonds and colored gemstones, there is no internationally recognized system for grading pearls. As a consequence, there are many systems in use.
What they all have in common is that they take the 6 most important factors in account. They are the 4-S and 2-C factors.

4-S factors

- Size
- Shape
- Shining (orient)
- Spots (blemishes)

2-C factors

- Color
- Coating (thickness of the nacre)

Images



Figure 16.51.8***:*** *12.5 mm Black Tahitian Pearl Strand*
Photo by Jeff Scovil
Courtesy of R.W. Wise Goldsmiths



Figure 16.51.9***:*** *White and Golden South Sea pearl strand*
Photo by Jeff Scovil
Courtesy of R.W. Wise Goldsmiths



Figure 16.51.10***:*** *Melo melo pearl*
Photo courtesy of Scott Davies, Americanthai.com

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16.51.01: Sea of Cortez Pearl

Pearl	
Chemical composition	Calcium carbonate, conchiolin and water
Crystal system	Amorphous
Hardness	2.5-3.5
Refractive index	1.52-1.69
Specific gravity	2.68-2.86
Lustre	Pearly



Figure 16.51.1.1***:*** *Sea of Cortez pearls®*
Photo Courtesy of Douglas McLaurin Moreno, Perlas del Mar de Cortez

"Perlas del Mar de Cortez" or "Sea of Cortez Pearls" are also known under the commercial name of "Cortez Pearl", a trade-name owned by Columbia Gem House-Tri-Gem Designs. These pearls are produced in the Gulf of California's coastal city of Guaymas, Sonora, Mexico, inside a tranquil Bay known as "Bacochibampo Bay". The pearl farm is owned by "Cultivadores Mexicanos de Perlas S.C.L." since 2004, and was previously owned by the ITESM Education System. It originated as a humble school project (1993) led by four researchers: Enrique Arizmendi Castillo, José Manuel Nava Romo, Douglas McLaurin-Moreno and Sergio Farell Campos. Further funding from ITESM helped to expand this operation into a commercial venture in the year 2000.

The farm is unique for many reasons, but mainly for being the only pearl farm in the world to utilize a pearl oyster of genus *Pteria* to produce its cultured pearls. All other marine pearl farms employ *Pinctada* genus species to grow their pearls.

Color

The *pteria sterna* mollusk is the species used to grow this unusual pearl. The common names for this species are: "Rainbow lipped pearl oyster", "Western Winged Pearl Oyster", "Concha Nácar" and "Callo de árbol". This oyster (Family Pteriidae) is capable of producing pearls in many colors -ranging from white to black, but gray, purple, lavender and blue are more common than white or black- and with varied overtones (such as blue, green, violet, purple and golden). The pearls are sometimes described as "opalescent" or as "abalone pearls" because of their unusual coloration. This coloration is due to several factors, one being its extremely good nacre coating, and the other one is a series of patterns that form on the surface of a pearl. When seen under a microscope these will resemble a human “finger-print”. Mexican Pearls display two features: an unusually compact structure of its aragonite crystals –seen at 500 nanometers- and the display of “spiraled” sub-patterns, which are unique to these pearls.

Shapes

Round and near-round shapes are exceptionally rare and account for less than 3% of a harvest. Semi-baroque (symmetrical: ovals, drops, buttons) shapes are more common with 25% and baroque (asymmetrical) shapes account for 71% of a harvest.

Sizes

The average size of the Sea of Cortez pearl is 8.9 mm, ranging in size from 8.3 to 9.8 mm, but they can get as large as 14.3 mm. Sizes above 10 mm in diameter account for only 5% of a pearl harvest.

Nacre Coating

A minimum of 0.8 mm to a 2.3 mm of nacre coating is expected after the 18-24 month culture period. Pearls with a coating below 0.8 mm are destroyed.

Production

Both Cultured and Mabe Pearls are produced. Production has been stable at less than 4 kilos per year, due mainly to problems caused by hurricanes but also by choice: High -quality production is attained with a controlled harvest. Mabe Pearl production is also limited to some 4-6 thousand per year.

- 2004: 2.8 kilograms
- 2005: 2.5 kilograms
- 2006: 2.8 kilograms

With an average weight of 1 gram per pearl, the yearly production is about 2,800 pearls.

Treatments

These pearls are untreated: no polishing, bleaching, irradiation, coating or artificial dyeing is performed on them. After harvest, pearls are soaked in water and then pat dried. The Sea of Cortez Pearl (or “Cortez Pearl”) is the only pearl in the gem industry that completely qualifies under the Fair Trade Gems protocols.

Fluorescence

The shell and pearls of the *Pteria sterna* oyster display a unique fluorescence under long-wave ultraviolet (UV) light, thus this pearl is able of displaying a blood-red to faint-pink glow. All other pearls (regardless of their origin) are inert (do not glow) under this same light.

Sources

- Sea of Cortez Pearls

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16.51.02: Quahog

Also known as “The Northern Quahog” or “Hard Clam,” this marine bivalve is found along the eastern seaboard of the United States from Maine to Florida, and is especially common from Massachusetts to New Jersey

Its name is generally pronounced as KO-hog, although “kwag” or “KWA-hog” is also used in some regions of Rhode Island, USA, and derives from the Narragansett Indians’ name for the clam, "poquauhock.” The interior lip of the clam’s shell is commonly colored light to royal purple to dark purple in stark contrast to the remainder of the mostly-white shell. This segment of the shell was ground into purple beads by Native Americans living along the eastern seaboard of the United States to form “wampum,” an important item of barter among Native Americans. Hence this species of bivalve carries the scientific name of *Mercenaria mercenaria*, derived from the Latin word for “money”. (Older references may cite this bivalve as *Venus mercenaria*, but it was reassigned by biologists.)

Quahog Pearls

The Quahog sometimes produces concretions of shell material which range in shape from flattened disks (aptly described as “shaped like an M&M candy”) to spheres, and in color from white to pale purple to a deep purple-black. **These concretions lack the lustrous nacreous layers that are characteristic of gem pearls** derived from oysters and are composed of layers of aragonite crystals interspersed with organic material.

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16.52: Pectolite

Pectolite	
Chemical composition	$NaCa_2Si_3O_8(OH)$
Crystal system	Triclinic
Habit	Aggregate
Cleavage	perfect
Fracture	uneven
Hardness	5
Optic nature	Biaxial +
Refractive index	1.59 - 1.63
Birefringence	0.028-0.038
Dispersion	Very weak
Specific gravity	2.62 - 2.87
Lustre	Silky
Fluorescence	Green (SW & LW-UV)

Varietal Names: “Larimar” is a blue pectolite from the Dominican Republic; the name “Larimar” is trademarked.

Crystal Habit

Crystals are uncommon and are usually tabular. More commonly occurs as bundles of acicular needles showing either columnar or radiating fibrous structure.

Chemical composition

Sodium calcium silicate hydroxide, NaCa2Si3O8(OH). Minor to trace amounts of iron, potassium, and copper may be present.

Diagnostics

Color

Colorless, white, pale apple green, dark green; the Larimar variety varies from white to light-medium blue (similar to turquoise) to green.

Magnification

The “Larimar” type of pectolite displays opaque red dendritic hematite, inclusions of translucent to transparent square patches of calcite to 2 mm wide, sprays of transparent to translucent grey natrolite as long prisms with square cross-section, opaque blebs of native copper, and opaque blebs and euhedral crystals of chalcocite, a copper sulfide Woodruff (1989). This same assemblage of accessory minerals is present in other, non-gem quality pectolite occurrences, such as the basalts of Paterson, New Jersey.

Cleavage

Perfect on {100} and {001}.

Specific Gravity

2.84 to 2.90 (measured), 2.97 (calculated).
Measurements of the specific gravity of Larimar ranged from 2.62 to 2.87; low range readings were probably a result of inclusions of other minerals in the pectolite.

Refractive Index

nα = 1.592 – 1.610, nβ = 1.603 to 1.615, nγ = 1.630 – 1.645

Fluorescence

Woodruff and Fritsch (1989) report a turbid green fluorescence under Short Wave ultraviolet radiation and a chalky green fluorescence under Long Wave for Larimar.

Phenomenon

Larimar may exhibit localized areas that appear chatoyant resulting from oriented parallel clusters of pectolite needles.

Treatments

None known

Synthetics

None known

Imitations

None known

Occurrence

Occurs in cavities in basalts and diabases as a result of hydrothermal action.

The Larimar variety of pectolite occurs in a basalt formation about 5km west of Baoruco, Dominican Republic; the pectolite was first discovered in 1974 as stream-rounded pebbles in an adjacent river.

In 1884, Frank W Clarke reported that a number of Eskimo artifacts collected near Point Barrow, Alaska – originally believed to be jade - were, in fact, composed of a “interesting variety of compact pectolite, in two varieties, one pale apple green, the other dark green” [cited in Kunz (1892)]. Apparently, the original source of the pectolite has not been found. Kunz also notes in 1887 geologist William P. Blake reported the discovery of a significant occurrence of compact, translucent pectolite that was “white, with a delicate shade of sea green” in color in Tehama County, California.

Care and Maintenance

Pectolite can be decomposed by mineral acids into a colorless silica gel; care should be exercised in the use of chemical cleaning

agents.

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16.52.01: Larimar

Larimar	
Chemical composition	$NaCa_2Si_3O_8(OH)$
Crystal system	Triclinic
Habit	Aggregate
Hardness	5
Optic nature	Biaxial +
Refractive index	1.59 - 1.63
Birefringence	0.028-0.038
Dispersion	Very weak
Specific gravity	2.62 - 2.87
Lustre	Silky
Fluorescence	Yellow or orange (SW-UV)

A blue pectolite found in the Dominican Republic. See pectolite

Acknowledgments and External Links

Gems & Gemology, Winter 1989 Issue Larimar
Blue Pectolite from the Caribbean

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16.53: Peridot

Peridot	
Chemical composition	$(Mg,Fe)_2SiO_4$
Crystal system	Orthorhombic
Habit	Prismatic
Cleavage	Poor
Fracture	Conchoidal
Hardness	6.5
Optic nature	Biaxial +
Refractive index	1.65 - 1.69
Birefringence	0.036
Dispersion	Medium, 0.020
Specific gravity	3.34
Lustre	Vitreous
Pleochroism	Weak



Figure 16.53.1***:*** *Flawless faceted Peridot*
Photo courtesy of Lembeck Gems

Magnification

Peridot is a Type II stone in the GIA clarity grading system is usually included. Typical inclusions are:

- disc like liquid and gas inclusions: "lily pads"
- dark, octahedral chromite crystals



Figure 16.53.2***:*** *Lily Pad inclusions displaying doubling*
35X Magnification
By Barbra Voltaire

The disc-like liquid and gas inclusions, often referred to as lily pads, appear doubled because of the strong birefringence that is a diagnostic characteristic of the gem.

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16.54: Phenakite

Phenakite	
Chemical composition	Beryllium sillicate Be_2SiO_4
Crystal system	Trigonal
Habit	Tabular to prismatic
Fracture	Conchoidal (brittle)
Cleavage	Indistinct (one direction)
Hardness	7.5 - 8
Optic nature	uniaxial +
Refractive index	1.651 - 1.670
Birefringence	0.016
Dispersion	Low, 0.015
Luster	Vitreous
Specific gravity	2.92 - 2.97
Pleochroism	Seen in strongly coloured stones
Fluorescence	Sometimes pale greenish / blue or pale rose



Figure 16.54.1***:*** *A faceted colorless gem-quality phenakite.*
Photo courtesy of Chaman Golecha, Gem Testing Laboratory, Jaipur

Crystallography

Trigonal system.
Habit: Tabular, prismatic, rhombohedral, acicular.

Diagnostics

Diaphaneity

Transparent.

Color

Colorless; also yellow, pink, brown, pinkish red due to surface stains.

Refractometer

Phenakite is uniaxial with a positive optic sign.
Refractive index range: n_ω = 1.651-1.654 and n_ε = 1.663-1.670.
The full birefringence is 0.016.

Polariscope

Not many gemstones are uniaxial + (zircon, quartz, phenakite and some idocrase). Finding the optic sign with the use of a retardation filter should narrow down the possibilities.
Quartz will almost always show a typical bull's-eye pattern (or Airy spirals).

Spectrum

Nothing diagnostic.

Fluorescence

Phenakite sometimes shows pale greenish / blue or pale rose fluorescence in UV light.
Under X-ray it fluoresces blue.

Pleochroism

Dichroism in observed in strongly colored stones.

Magnification

May have many needle inclusions; 2-phase; fingerprints with phase inclusions.

Simulants

Name	
Spodumene	Magnifica
Sillimanite	
Rock Crystal	Lowe
Topaz	M
Zircon	

Occurrence

Geological occurrence: Commonly in pegmatites, mica schists, in granite drusses.

Geographical locations: Tokajawa river, Ural Mountains with emerald and chrysoberyl; Miask district, Rissia; large colourless crystals at San Miguel di Praciavaba, Minas Gerais; Tanzania; Maine, New Hampshire & Colarado, USA; Switzerland; Austria; Alsace, France; Namibia; Norway and Sri Lanka (large stone).

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16.55: Pouretteite

Poudretteite	
Chemical composition	$KNa_2B_3Si_{12}O_{30}$ Borosilicate
Crystal system	Hexagonal
Habit	Hexagonal and barrel-shaped etched prisms
Cleavage	None
Fracture	Conchoidal, splintery
Hardness	5-6
Optic nature	Uniaxial +
Refractive index	1.510 - 1.532
Birefringence	0.016 - 0.021
Dispersion	Unknown
Specific gravity	2.50 - 2.55
Lustre	Vitreous
Pleochroism	Colorless to pink, depending on body color



Figure 16.55.1***:*** *Podreitteite*
Photo courtesy of Scott Davies, americanthai.com

A very rare gem, first found in Mont St. Hilaire, Quebec, Canada. Named after the Poudrette family who were the operators of the quarry where it was first discovered.

Color

Colorless to pink, purple.

Transparency

Transparent.

Crystal habit

As stubby, barrel-shaped prismatic or bipyramidal crystals.

Chemical composition

$KNa_2B_3Si_{12}O_{30}$ Potassium sodium boron silicate.

Diagnostics

Poudretteite could be mistaken for feldspar and scapolite.
Feldspar, however, has a biaxial optical nature and scapolite is uniaxial with a negative optic sign.

Specific gravity

2.51(Measured), 2.53 (Calculated)
Scapolite has a SG range of 2.634 to 2.74 and feldspar has a range of 1.52 to 1.57.

Tenacity

Brittle.

Refractive Index

nω = 1.516, nε = 1.532
Poudretteite has a uniaxial optical nature with a positive optical sign.

- Scapolite (n = 1.545 - 1.580) also has a uniaxial character, but has a negative optical sign. Although the readings are somewhat high to indicate poudretteite, the birefringence is similar.
- Feldspars (n = 1.52 - 1.57) are biaxial with a positive or negative optical sign.

Birefringence

The birefringence varies from 0.016 to 0.021 and produces a noticeable doubling of facets.

Pleochroism

Colorless to pink.

Spectroscope

No known diagnostic spectrum in the visible range.

Luminescence

None observed.

Magnification

Inclusions may include veils of two-phase (liquid + gas) inclusions and localized parallel flat tubes.

Treatments

None known.

Synthetics

None known.

Imitations

None known.

Care

Poudretteite is a very rare gem and no special vulnerabilities are reported, besides its brittleness.

Phenomenon

None known.

Occurrence

Poudretteite was originally described in 1987 as minute crystals of no gemological interest at Mont St. Hilaire; the samples had been collected in the 1960's. In 2000, rough was discovered in the Pain Pyit district, Mogok, Myanmar that cut a 3ct stone that was later determined to be poudretteite. As of 2004, 10 examples of poudretteite had been identified amoung Mogok stones, the largest being a 22ct crystal that was cut into a 9.4ct gem.

Facet grade poudretteite is also found in Mogok, Burma. As of mid-2007, about 30 small pieces of rough have been recovered. Most produce small gems, and clean stones weighing in excess of 1 carat remain elusive. Some gems are pink in tone, but these also are not common.

Sources

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- Anthony, John W., Bideaux, Richard A., Bladh, Kenneth W., and Nichols, Monte C. (1990): Handbook of Mineralogy: Mineral Data Publishing, Tucson, Arizona
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- Smith, Christopher P., Bosshart, G., Graeser, S., Hanni, H. and Gunther, D. (2003) Gems and Gemology Vol 39 No. 1 Poudretteite: A Rare Gem Species from the Mogok Valley

External links

- Mont St. Hilaire

- Canadian Mineralogist Vol.25 Poudretteite

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16.56: Prehnite

Prehnite	
Chemical composition	$Ca_2Al_2Si_3O_{10}(OH)_2$+Fe
Crystal system	Orthorhombic
Habit	Usually Fibrous Aggregate
Cleavage	Good:1 direction
Fracture	Uneven-Conchoidal
Hardness	6-6.5
Optic nature	Biaxial (+) Aggregate
Refractive index	1.649-1.616
Birefringence	.020-0.031
Specific gravity	2.90
Lustre	Vitreous-Pearly



Figure 16.56.1***:*** *Prehnite cabochon*
Photo courtesy of Barbra Voltaire



Figure 16.56.2***:*** *Prehnite crystals*
Photo courtesy of Barbra Voltaire

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16.57: Pyrite

Pyrite	
Chemical composition	FeS_2
Crystal system	Cubic
Habit	Cubic, faces may be striated, but also frequently octahedral and pyritohedron. Often inter-grown, massive, radiated, granular, globular and stalactitic.
Cleavage	Indistinct on {001}; partings on {011} and {111}
Fracture	Very uneven, sometimes conchoidal
Hardness	6–6.5
Refractive index	a = 1.730; b = 1.758; y = 1.838
Specific gravity	4.8-4.9
Lustre	Metallic



Figure 16.57.1***:*** *Victorian Pyrite-set Lizard Pins*
Photo courtesy of Barbra Voltaire

Marcasite is a misnomer, referring to the mineral pyrite when it is faceted into small reflective stones and used in jewelry. Marcasite and pyrite are both iron disulfides but they are different minerals because they crystallize in different systems and form under different geologic conditions. Marcasite isn't suitable for use in jewelry because it is unstable and can decompose in the air, appearing to acquire a chalky coating. Pyrite is named after the Greek word for fire as it produces sparks when struck by iron.



Figure 16.57.2***:*** *Pyrite Crystals, Spain*
Photo courtesy of Barbra Voltaire

Pyrite crystallizes in the cubic system and can form perfect cubes with shiny metallic gold faces. Native Americans believed that pyrite "mirrors" allowed you to see inside the soul.

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16.58: Rhodochrosite

Rhodochrosite	
Chemical composition	$MnCO_3$ + Fe, Ca
Crystal system	Hexagonal
Habit	Rhombohedral
Colors	pink, red, yellowish, gray, brown
Hardness	3.5 - 4
Specific gravity	3.40 - 3.70
Optic nature	Uniaxial -
Refractive Index	1.60 - 1.83
Birefringence	0.208 - 0.220
Lustre	Vitreous to pearly



Figure ($PageIndex1$***:*** *Spectacular Cabochon 60x30mm*
Capillitas, Catamarca Province, Argentina
Photo courtesy of Barbra Voltaire

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16.59: Sapphirine



Figure 16.59.1***:*** *From Kolonne,Sri lanka*

Sapphirine is a rare mineral, a silicate of magnesium and aluminum with the chemical formula (Mg,Al)8(Al,Si)6O20 (with iron as a major impurity). Named for its sapphire-like color, sapphirine is primarily of interest to researchers and collectors: well-formed crystals are treasured and occasionally cut into gemstones. Sapphirine has also been synthesized for experimental purposes via a hydrothermal process.

Chemical composition

(Mg,Al)8(Al,Si)6O20

Typical colors range from light to dark sapphire blue, bluish to brownish green, green, and bluish or greenish-gray to black; less common colors include yellow, pale red, and pink to purplish pink. Sapphirine is relatively hard (7.5 on Mohs scale), usually transparent to translucent, with a vitreous lustre. Crystallizing in the monoclinic system, sapphirine is typically anhedral or granular in habit, but may also be tabular or in aggregates: Twinning is uncommon. Fracture is subconchodial to uneven, and there is one direction of perfect cleavage. The specific gravity of sapphirine is 3.54–3.51, and its streak is white.

Color

Dark blue, bluish to brownish green, green, gray.

Diaphaneity

Transparent to opaque.

Refractometer

1.701 to 1.718 with a Birefringence 0.006 to 0.007.

Specific gravity

The specific gravity of Sapphirine is 3.54–3.51.

Occurrence

Large crystals of fine clarity and color are known from very few locales: The Central Province (Hakurutale and Munwatte) of Sri Lanka has long been known as a source of facetable greenish blue to dark blue material, and crystals up to 30 mm or more in size have been found in Fianarantsoa (Betroka District) and Toliara Province (Androy and Anosy regions), southern Madagascar. Sapphirine's type locality is Fiskenaesset (Fiskenaes), Nuuk region, western Greenland, which is where the mineral was discovered in 1819.

Synthetics

Crystals have been produced with the hydrothermal method for experimental purposes.

Sources

- Wikipedia

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16.60: Scapolite

Scapolite	
Chemical composition	Complex sodium aluminium silicate
Crystal system	Tetragonal
Habit	Prismatic and massive
Cleavage	Distinct to perfect (depending on direction)
Fracture	Conchoidal
Hardness	6
Optic nature	Uniaxial -
Refractive index	1.545-1.580 (depending on color)
Birefringence	0.016-0.02
Dispersion	Low, 0.017
Specific gravity	2.634-2.74 (depending on color)
Lustre	Vitreous
Pleochroism	Medium to strong (depending on color)

Diagnostics

Polariscope

Scapolite can be easily confused with quartz - in particular the violet version with amethyst - due to overlapping refractive indices. The optic character for scapolite is uniaxial with a negative sign while quartz is uniaxial with a positive sign. In addition; quartz will usually show a bull's-eye. Separating the two is, in general, an easy task (30 seconds) when one is familiar with the conoscope addition to the polariscope.

Tenebrescence



Figure 16.60.1***:*** *Tenebrescent scapolite before and after exposure to UV light. Photo courtesy of Scott Davies, americanthai.com*

A fairly recent find (2005) in Badakhshan, Afghanistan is tenebrescent scapolite. This colorless to silvery material is unearthed

near the hackmanite deposits and shows an aquamarine color after exposure to SWUV light. The intensity of this color (blue) depends on the time it has been exposed to the UV lighting. Exposure to a UVP UVG4 SWUV lamp for 15 minutes triggered an almost Santa Maria aquamarine blue color that faded gradually during the following 2-3 minutes in natural daylight.

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16.61: Serendibite

Serendibite	
Chemical composition	$Ca_2(Mg,Al)_6(Si,Al,B)_6O_{20}$
Crystal system	**Triclinic**
Habit	**Tabular/Granular**
Cleavage	**None**
Fracture	**Sub-concoidal, uneven**
Hardness	**6-7**
Optic nature	**Biaxial (+) or (-)**
Refractive index	**1.701-1.706**
Birefringence	**.005**
Specific gravity	**3.42-3.52**
Lustre	**Vitreous**
Pleochroism	**Strong** X: pale yellow, yellow-green to blue-green Y: almost colorless, pale yellow, blue-green, blue Z: pale blue to dark blue

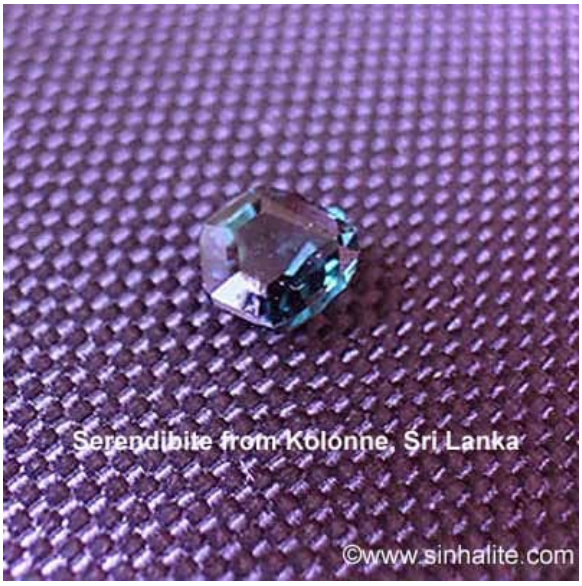


Figure 16.61.1***:*** *Serendibite from Kolonne,Sri Lanka*
Photo courtesy of Sinhalite.com

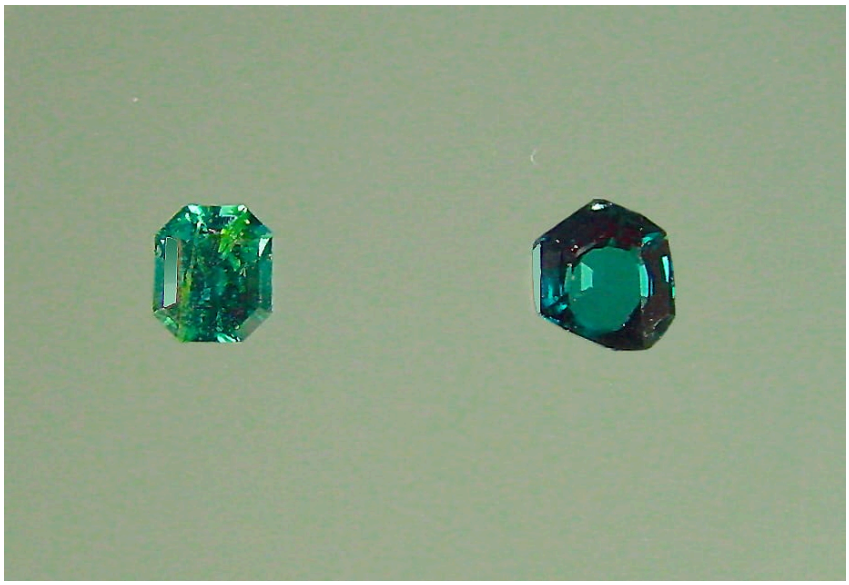


Figure 16.61.2***:*** *Faceted Sri Lankan Serendibites*
Microscopic features:
Isolated twin lamellae, partially healed fissure, fracture, tiny mineral inclusions, polysynthetic twinning
Photo courtesy Mr. George Bosshart, research gemologist from Horgen-Zurich, Switzerland

Occurrence

Serendibite was discovered at Gangapitiya, near Ambakotte, Sri Lanka, in 1902 by G.T. Prior and A.K. Coomaraswamy. Prior and Coomaraswamy named the mineral 'serendibite,' which is derived from 'serendib,' an old Arabic term for Sri Lanka.

Serendibite is rarely found as facet-grade material. Before the 2005 discovery of serendibite in Mogok, Myanmar, there were only 3 known faceted serendibites, which were from the original Sri Lankan find. The serendibite from Sri Lanka and Myanmar is believed to be the only sources for facet-grade material. Sri Lankan Serendibite was an attractive greenish or violet-blue, while the stones from Myanmar are dark black.

In the second half of the 1990's, gem-quality serendibite was discovered from secondary deposits in the Ratnapura area of Sri Lanka.

The rare gem material, serendibite, is characterized with regard to gemological, chemical, and spectroscopic properties. Spectroscopic features such as US-Vis-NIR and infrared ranges, as well as Raman and photoluminescence data, are considered more for identification of serendibite.

Serendibite may be confused with sapphirine and zoisite due to similarity in color and almost identical properties but refractive indices, twinning, and spectra can be used to separate these gem materials.

The distinction from sapphirine and the known low-bearing, gem-quality serendibite can be made by careful measurement of refractive indices, with sapphirine having a higher refractive index of 1.700. Higher contents of iron in serendibite may cause misleading refractive index readings and may require further gemological examinations such as spectroscopy and microscopy.

The optical properties and specific gravity of serendibite and zoisite may completely overlap. The color of the chromium and chromium-bearing Tanzanian zoisite is quite similar to serendibite. A distinction may be made on the basis of the lamellar or polysynthetic twinning of gem-quality and non-gem quality serendibite samples from various locations.

Geological occurrence:

It "occurs in skarns, affected by boron metasomatism, along the contact between carbonate rocks and granite, tonalite, or granulite."

Geological distribution: Sri Lanka: Gangapitiya, near Ambakotte Myanmar: Mogok USA: near Johnsburg, Warren Co., Amity, near Warwick, Orange Co., and Russell, St. Lawrence Co., New York; and in the New City quarry, 3km south of Riverside, Riverside Co., California Canada: Melville Peninsula, Northwest Territories Russia: Tayozhnoye iron deposit Tanzania: 550 km south of Yakutsk, Yakutia, from the Handeni district Madagascar: Ianapera and Ihosy.

Chemical composition

Combination of calcium, magnesium, aluminum, silicon, boron and oxygen.

Color



Figure 16.61.3***:*** *Black Serendibite, Mogok*
Photo courtesy of House of Onyx

Grayish blue-green to deep blue, black, green, or brown; in transmitted light, nearly colorless to pale yellow-green or blue.

UV fluorescence:

Long wave: Inert
Short wave: Inert

References and Additional Information

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- Speer, Dr. J. Alexander, Executive Director, Mineralogical Society of America, 3635 Concorde Pkwy Suite 500, Chantilly, VA, 20151-1125, USA, **Handbook of Mineralogy**

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16.62: Siderite

Siderite

Siderite	
Chemical composition	$FeCO_3$
Crystal system	Trigonal
Habit	Rhombohedrons, ganular, oolites
Cleavage	Perfect, rhombohedral {101}
Fracture	
Hardness	3.5 - 4.5
Optic nature	Uniaxial -
Refractive index	1.633 - 1.875
Birefringence	0.240
Dispersion	
Specific gravity	3.83-3.88 (upto 3.96)
Lustre	Vitreous, pearly, silky or dull
Pleochroism	



Figure 16.62.1***:*** *A rare faceted siderite. Notice the, easily visible, doubling of facet edges. Photo by Chaman Golecha, Gem Testing Laboratory, Jaipur*

Crystallography

Trigonal system.
Habit: rhomb shaped; massive; granular; globular; oolitic

Chemical composition

$FeCO_3$ - iron carbonate.
Siderite belongs to the calcite group and forms series with rhodochrosite and magnesite.

Diagnostics

This stone is too soft to be cut and is hence rarely faceted as a gemstone. As it is a carbonate, it would give effervescence (bubbling) when in contact with acids; strong eye visible doubling due to the high birefringence. Siderite, like most carbonates, is highly birefringent.

Color

Pistachio brown (gem). Also pale yellowish-brown; pale yellowish; pale green; greenish-gray; grayish brown; reddish-brown; blackish brown; rarely almost colorless. Also massive.

Diaphaneity

Transparent to opaque.

Specific gravity

S.G.: 3.83-3.88 (up to 3.96), siderite will sink in all common heavy liquids.

Refractometer

Optic nature: birefringent, uniaxial negative.
Refractive index: $n_\omega = 1.875$, $n_\varepsilon = 1.633$.
Maximum birefringence: 0.240.
On a gemological refractometer, only the extra-ordinary ray may be observed. The shadow edge (of the extra-ordinary ray) will move while there is no constant ordinary reading (above the range of the refractometer). Care should be taken not to mistake the constant shadow of the liquid for the real ordinary ray.

Spectrum

Not very characteristic; band at 530, 500nm; vague at 440-480; strong 450, 475, 420 giving a cut-off like appearance.

Luminescence

UV fluorescence: generally inert.

Inclusions

Strong doubling of inclusions and pavilion facet edges due to very high birefringence.

Occurrence

Geological occurrence:
A widespread mineral in sedimentary deposits; hydrothermal ore veins; also in pegmatites; basaltic rocks.

Geographical locations:
Pinasquevia, Portugal: brown fine transparent material; Also Colorado; Connecticut; Idaho; Austria; France; Germany; Italy; Brazil (large fine); Quebec, Canada (brown rhombs); Greenland (rich brown, gemmy in cryolite); England, Cornwall (transparent known as

'Chalybite').

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16.63: Sodalite

Sodalite	
Chemical composition	Sodium aluminum silicate
Crystal system	Cubic
Habit	Massive
Cleavage	Distinct, dodecahedral
Fracture	Conchoidal to uneven
Hardness	5.5-6.0
Refractive index	1.478-1.488
Birefringence	None
Specific gravity	2.27
Lustre	Vitreous to greasy

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16.64: Hackmanite

Hackmanite	
Chemical composition	Natrium aluminium silicate
Crystal system	Cubic
Habit	Aggregate
Hardness	5 - 6
Refractive index	± 1.48
Specific gravity	2.15 - 2.40



Figure 16.64.1***:*** *Tenebrescent Hackmanite before exposure to sunlight*
Photo courtesy of The Gem Trader



Figure 16.64.2***:*** *Tenebrescent Hackmanite after exposure to sunlight*
Photo courtesy of The Gem Trader

Hackmanite is the name given to natural Sodalite which has unique properties of fluorescence. While Hackmanite from Afghanistan and Burma are the same mineral, different ions, including but not limited to Sulfur, cause the stones to react differently.

Afghan Hackmanite, while not common, can be clean enough to facet. Burmese Hackmanite is translucent at best, but is often opaque.
Afghan Hackmanite is colorless to very light pink or violet in its natural state. Burmese Hackmanite can be light to medium gray, light blue, light pink or light violet.
When subjected to SW UV lighting, Afghan Hackmanite will darken to light to medium violet over a period of 3-5 minutes. Burmese Hackmanite, however, will darken to intense dark violet in a matter of seconds.
Sunlight has no effect on most Afghan Hackmanite. Burmese Hackmanite, however, will gradually darken before your eyes over a period of 3-5 minutes when exposed to sunlight.
Afghan Hackmanite will fade to its original lighter tone in a matter of seconds or minutes. Burmese Hackmanite, however, once 'charged' with sunlight or SW UV, will gradually and very slowly fade over a period of 1-7 days.

Click here for GemologyOnline's Hackmanite Article

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16.65: Sphalerite

Sphalerite	
Chemical composition	(Zn,Fe)S
Crystal system	Cubic
Habit	Tetrahedral or dodecahedral
Cleavage	Perfect in 6 directions; easily developed
Fracture	Concoidal to uneven
Hardness	3.5-4.0
Optic nature	Isotropic
Refractive index	2.368 - 2.500 (increases with Fe content)
Specific gravity	3.95-4.10
Lustre	Adamantine to Subadamantine



Figure 16.65.1***:*** *Round Brilliant Sphalerite*
Photo courtesy of
Rick Martin, Art Cut Gems

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16.66: Sphene

Sphene

Sphene	
Chemical composition	$CaTiOSiO_4$
Crystal system	Monoclinic
Habit	Wedge shaped, massive
Cleavage	Distinct, prismatic
Fracture	Conchoidal
Hardness	5.0-5.5
Optic nature	Biaxial +
Refractive index	1.880-2.099
Birefringence	0.100-0.135
Dispersion	High, 0.051
Specific gravity	3.45-3.55
Lustre	Resinous to sub-adamantine
Pleochroism	Distinct to strong



Figure 16.66.1***:*** *Green sphene from Madagascar. Photo courtesy of Scott Davies, americanthai.com*

Sphene image gallery

Sphene is the older name of this mineral which refers to its crystal shape. Titanite is the universal name amongst mineralogists today and refers to its content of titanium. Greenovite is the name given to red or pink sphene. Gemologists use the name sphene for gem material titanite.

Sphene is isostructural with tilasite, malayaite and fersmantite.

Habit

Wedge-shaped crystals that may show parting due to twinning. Less common massive or lamellar. Sphene is normally fine-grained but occasionally forms large crystals.

Sphene may show some degree of metamictization.

Diagnostics

Color

Yellow, brown, green, reddish.
Color is caused by rare earth elements (didymium) for yellow stones and chromium for the intense green chrome sphene.

Streak

White.

Diaphaneity

Transparent to opaque.

Refractometer

n_α = 1.843 - 1.950, n_β = 1.870 - 2.034, n_γ = 1.943 - 2.110 with a birefringence of 0.100 - 0.192.
Optical nature: biaxial positive.

A strong doubling of facets is seen in cut stones.

Polariscope

Due to its small to moderate 2V value (17-40°) a clear biaxial interference pattern may be seen (two melatopes visible in one image).

Pleochroism

Moderate to strong trichroism.
Yellow to brown stones: colorless, greenish-yellow, reddish.

Spectroscope

Sometimes a spectrum can be seen.
Mean absorption lines: 586, 582. Sphene may show (weak) rare earth spectra due to didymium.

Fluorescence

None (probably due to iron content).

Varieties

- Chrome sphene, intense green (color caused by chromium).
- Greenovite, a reddish variety owning its color to manganese (MnO) impurities.

Treatments

Sphene is changed to red or orange through heating.

Durability

Sphene's relative low hardness makes it vulnerable to abrasion.

Occurrence

Sphene is a common and widespread mineral in many igneous rocks and metamorphic rocks. Associated minerals are pyroxene, amphibole, feldspar and quartz.

Facet-grade sphene was found in Mulla Ghani Baba in Mohmand Agency, NW of Peshawar, Pakistan, in 2004. The color of this sphene is medium to dark brown, and a significant 'red flash' was notable in the faceted gems. In Badadkshan, Afghanistan, sphene was also found in 2004. The color of Afghan sphene is greenish-yellow. While India also produces fine sphene, Madagascar remains the main source for facet-grade sphene. While brown stones from Madagascar can be large, the green stones are most prized by gem collectors and connoisseurs.

Other deposits:
Myanmar, Sri Lanka, Brazil, Mexico, Russia and Austria

Sources

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- *Gemstones of the world, 3rd rev and exp edition* (2006) - Walter Schuman ISBN 1402740166
- *Mineralogy second edition* (2002) - Dexter Perkins ISBN 0130620998
- *Introduction to Optical Mineralogy* (2004) -
- Gemmology 3rd edition (2005) - Peter Read
- *Gem Reference Guide* (1995) - GIA ISBN 0873110293

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16.67: Taaffeite

Taaffeite	
Chemical composition	Magnesium-beryllium-aluminium oxide $Mg_3BeAl_8O_{16}$
Crystal system	Hexagonal
Hardness	8
Luster	Vitreous
Optic nature	Uniaxial -
Refractive index	1.717 - 1.724
Birefringence	0.004 - 0.005
Dispersion	0.019
Specific gravity	3.60 - 3.62
Pleochroism	Faint
Fluorescence	LW: inert to lightgreen SW: inert



Figure 16.67.1***:*** *Photo courtesy of The Gem Trader*

In mineralogy, taaffeite is the name of a polytype group to which also musgravite belongs. The current (2002) IMA approved name for taaffeite as a mineral is magnesiotaaffeite-2N'2S. Prior to 2002, it was known as just "taaffeite". When gemologists refer to "taaffeite", "magnesiotaaffeite-2N'2S" is usually implied.
Taaffeite is, to date (2007), the only mineral that was discovered as a faceted gemstone instead of a rough crystal.

Taaffeite is named after its discoverer, Count Edward Charles Richard Taaffe (1898-1967) who discovered the stone by chance in

October 1945 from a lot of gemstones bought from Dublin, Ireland based jeweler and watchmaker Robert Dobbie.
After examination of the lot with a microscope, hydrostatic balance, polariscope and immersion, he found a stone having properties close to spinel but showing double refraction. As he was puzzled by this cut gemstone (wondering if anomalous birefringence could be that strong), he sent the stone off to Basil Anderson at the Laboratory of the London Chamber of Commerce. There it was identified as a new mineral species.

Alternative name: Taprobanite (rarely used).

Diagnostics

Taaffeite can easily be mistaken for spinel judging from its refractive index and specific gravity range, but taaffeite is most definitely birefringent while spinel is not, although spinel can exhibit anomalous double refraction(ADR) due to internal stain. Therefore do not rely on polariscope reaction for identification, unless you are fortunate enough to detect an optic figure with the coniscope.
Distinguishing taaffeite from musgravite can be a challenge and usually requires laboratory techniques as Raman spectroscopy and energy dispersive X-ray fluorescency (EDXRF).

Color

The chromium colored red stones are the most rare of this rare gemstone species.

Colorless, grayish violet, violet red, red, greenish, light green, pink-violet, mauve.

Spectroscope

Iron colored taaffeite may show the same spectrum as iron-bearing spinel in the visible range.
Chromium rich taaffeite gemstones may have an absorption band around 550nm.

Occurrence

Taaffeite is predominantly found in Sri Lanka. Rare sources are Myanmar and Tanzania.

Sources

- Taaffeite and Musgravite article from the GAAJ
- Anderson B W, Payne C J, Claringbull G F, Hey M H (1951) Taaffeite, a new beryllium mineral, found as a cut gemstone, Mineralogical Magazine 29, 765-772 (from RRUFF)

- Gems Their Sources, Descriptions and Identification *4th Edition (1990) - Robert Webster (6th ed.)*
- *Two remarkable taaffeite crystals* - K. Schmetzer, L. Kiefert et al., Journal of Gemmology Vol. 29 No. 7/8, July/October 2005
- Count Richard Taaffe (1898-1967) Irish gemologist, discoverer of taaffeite (1945)

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16.68: Topaz

Topaz	
Chemical composition	$Al_2(F,OH)_2SiO_4$
Crystal system	Orthorhombic
Habit	Prismatic with pyramidal/domed terminations
Cleavage	Perfect, basal plane
Fracture	Sub-conchoidal to uneven
Hardness	8
Optic nature	Biaxial +
Refractive index	1.606-1.644
Birefringence	0.008 - 0.010
Dispersion	Low, 0.014
Specific gravity	3.49 - 3.57
Lustre	Vitreous
Pleochroism	Distinct to strong (depending on body color)



Figure 16.68.1***:*** *Peach Pink Imperial Topaz*
Photo courtesy of Lembeck Gems

Topaz image gallery

Topaz is an aluminum silicate mineral with varying amounts of fluorine (F) and hydroxyl (OH) which replace each other through isomorphous replacement. Extreme outer limits with only fluorine or only hydroxyl have not been reported.
As a gemstone, topaz is the birthstone of November and imperial topaz is used to celebrate the 23rd year of marriage.

Diagnostics

In color and diaphaneity, topaz can be confused with many gemstones like aquamarine, zircon, citrine, peridot, beryl and sapphire. All of these, with the exception of peridot, are uniaxial while topaz is biaxial. Peridot is also biaxial, but has higher refractive indices.

Color

Topaz is allochromatic and occurs in many colors.

- Colorless
- Yellow - colored by color centers
- Green
- Blue - colored by color centers, irradiation/heat treatment
- Red - colored by chromium
- Pink - colored by chromium, heat treatment
- Orange - colored by color centers and chromium
- Brown - colored by color centers

Diaphaneity

Transparent.

Refractometer

Topaz with high concentrations of fluorine has a lower refractive index (1.61-1.62) than those with high concentrations of hydroxyl (1.63-1.64).

The optic character of topaz is biaxial with a positive optic sign
Full refractive index range: n_α = 1.606-1.634, n_β =1.609-1.637 , n_γ = 1.616-1.644 with a maximum birefringence of 0.008-0.010 (depending on content of fluorine and hydroxyl).

Other stones falling in the refractive index range are apatite, andalusite, danburite and tourmaline.

Specific gravity

As with the refractive index, the specific gravity changes with high concentrations of hydroxyl and fluorine.
Hydroxyl causes a lower specific gravity (3.53) while fluorine raises the specific gravity of topaz (3.56).

Topaz sinks in all common heavy liquids while apatite, andalusite, danburite and tourmaline will float in methylene iodide (sg = 3.33).

Dichroscope

The pleochroism is usually moderate and almost dichroic, except for heated pink stones where it is more profound.

Durability

Topaz has perfect cleavage in the direction of the basal plane (001), so care should be taken not to knock the gemstone.

Phenomena

Cat's-eyes.

Inclusion images



Figure 16.68.2***:*** *2-phase inclusions in colorless topaz.*
Photo courtesy of John Huff, gemcollections.com

Topaz inclusions gallery

Treatments

Irradiation followed by heat treatment to create blue stones and heat treatment of brownish stones to create pink gemstones. The irradiation process to create blue stones could make them radioactive and a "cooling down" period is usually taken into account. After that period these stones are perfectly safe.

Imitations

Recently,2007, yellow-orange-pink flame-fusion corundum is offered in Minas Gerais, Brazil as imperial topaz.

Synthetics

Although topaz is synthesized, the material is not commercially available for gemstones.

Sources

- From Gems & Gemology: A New Imitation of Imperial Topaz

- Gems Their Sources, Descriptions and Identification *4th Edition (1990) - Robert Webster (6th ed.)*
- *Gem-A* Foundation and Diploma notes
- Introduction to Optical Mineralogy *3rd edition (2003), Prof. W.D. Nesse*
- *Gem Reference Guide* (1995) - GIA ISBN 0873110293
-

External links

- Son of Franken-stone: An Update on Irradiated Gemstones from Pala International

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16.69: Turquoise

Turquoise	
Chemical composition	$CuAl_6(PO_4)_4(OH)_8.5H_2O$
Crystal system	Triclinic
Habit	Botryoidal, massive, microcrystalline to granular
Fracture	Conchoidal
Hardness	5.0 - 6.0
Refractive index	1.610-1.650
Specific gravity	2.30-2.90
Lustre	Waxy



Figure 16.69.1***:*** *Persian turquoise*

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16.70: Vesuvianite

Vesuvianite	
Chemical composition	Complex calcium aluminum silicate
Crystal system	Tetragonal
Habit	Prismatic terminated by truncated pyramids, massive, fibrous
Cleavage	Poor
Fracture	Sub-conchoidal
Hardness	6.5
Optic nature	Uniaxial +/-
Refractive index	1.700 - 1.725
Birefringence	0.005
Dispersion	Low, 0.019
Specific gravity	3.25-3.50
Lustre	Vitreous
Pleochroism	Weak to distinct (shades of body color)



Figure 16.70.1***:*** *Faceted vesuvianite*

Synonyms: Idocrase

Vesuvianite takes its name from Mount Vesuvius, the famed volcano in Italy, where the mineral was first found; it was named in 1795 by the famous mineralogist Abraham Gottlob Werner. The French mineralogist Rene Just Hauy suggested it should be named Idocrase four years later. Werner's name takes precedence.

Variental Names: Cyprine, Californite

Cyprine is a blue copper-containing variety of vesuvianite that was first described from Norway about 1821 by the famous mineralogist Berzelius; the name is derived from Cyprium, the ancient term for copper.

Californite is a compact massive form of vesuvianite that has an appearance to poor quality jade. It has historically been used as a jade simulant. It was first described by famed gemologist George Frederick Kunz in 1903, who suggested the name "californite" in honor of the state in which it was found. Dietrich (2005) offered the following opinion: "With all due regards to G.F. Kunz, I believe that... vesuvianite would have gained more "prestige" in gemology if the term californite had never been introduced." He added "...the use of any gem material as a simulant serves only to denigrate its use under its own name." Californite has also been called "American Jade", "California Jade", and "Vesuvianite Jade". Any usage of names for vesuvianite which include "jade"

should be discouraged.

Crystal System

Tetragonal or monoclinic (anomalously biaxial).

Crystal Habit

Prismatic to equant stubby crystals; massive granular to fine grained.

Chemical composition

Ca10Mg2Al4(SiO4)5(Si2O7)2(OH)4 often containing trace to minor amounts of iron, copper up to 2.1% as Cu in cyprine), chromium, manganese, titanium, boron or beryllium.

Diagnostics

Peridot has a lower refractive index (1.654 to 1.670). The californite variety of vesuvianite floats or sinks slowly in methylene iodide; jadeite sinks (specific gravity less than 3.3). Nephrite has a lower specific gravity (3.295).

===Color=== yellow, yellowish-green, green, emerald green, yellow-brown, brown, blue, violet to magenta; sometimes displays distinct color zoning.

Magnification

Under magnification, the cyprine variety may exhibit a distinctly fibrous appearance.

===Cleavage=== poor on {110}, {100} and very poor on {001}

===Specific Gravity=== 3.32 - 3.34 (measured); 3.42 (calculated)

Optical Nature

Uniaxial (+) or Uniaxial (-); biaxial vesuvianite has been observed.

Refractive Index

nω = 1.703 – 1.752 nε = 1.700 – 1.746.
The variety cyprine from Franklin New Jersey demonstrates a lower range of refractive indices, with nω = 1.696 – 1.712 nε = 1.710 – 1.719.
When iron or titanium replaces magnesium or aluminum, the values are usually increased (but not higher than nω = 1.752 and nε = 1.746).

Birefringence: approximately 0.005 The birefringence of vesuvianite can vary from 0.001 to 0.020, but is usually in the range of 0.001 to 0.009.

Antimony rich vesuvianite have RI indices at the higher end of the range with a birefringence of 0.020.

Pleochroism

Weak; nω = colorless to yellowish, nε = yellowish, greenish, brownish.

Spectroscope

No apparent diagnostic spectrum.

Treatments

None known.

Phenomenon

None known.

Synthetics

None known.

Imitations

None known.

Occurrence

Vesuvianite usually results from contact or regional metamorphism of limestones containing silica.



Figure 16.70.2***:*** *Rare violet colored vesuvianite crystals from the Jeffrey Mine described below*

The Jeffrey Mine in Asbestos, Quebec has afforded facet rough that is predominantly yellow-green in color, similar to peridot; the mine has also produced an emerald green chrome-bearing vesuvianite and a violet to magenta manganoan vesuvianite that is sometimes called “manganovesuvianite” (this term is too close to the name of a different, non-gem mineral species, “manganvesuvianite” for comfort and should be discouraged). Bicolored facetted stones consisting of yellow-green common vesuvianite on one side, and pale magenta manganoan vesuvianite on the other, have been cut. Italy – most notably Bellecombe in Val d’Aosta has produced greenish-brown to brown faceting rough. During the past decade, Fushan, Hebei Province, China has produced moderate quantities of deep yellow-brown (sometimes called “root beer”) colored crystals with gemmy areas capable of being facetted and cut en cabochon. Kaiiado District, Rift Valley Province, Kenya has produced greenish-yellow to yellowish-green

vesuvianite faceting rough.

Cyprine- The original Norwegian find was of no interest as a gem material, but a significant quantity of cyprite was uncovered in 1922 during mining at Franklin, New Jersey, about 850 feet underground. Reports have been made of facetted specimens of cyprine from Sri Lanka, Jakobsberg Mine, Värmland, Sweden, and Pakistan; all are a pale blue tinged with grey.

Californite- Northern California has produced Californite at several locations, including Happy Camp in Siskyou County, the Pulga Deposit on the North Fork of the Feather River, Butte County, and Tulare County.

Sources

- Anthony, John W., Bideaux, Richard A., Bladh, Kenneth W., and Nichols, Monte C. (1990): Handbook of Mineralogy: Mineral Data Publishing, Tucson, Arizona
- Dietrich, R. V. (2005): “Vesuvianite” (webpage at: http://www.cst.cmich.edu/users/dietr1rv/vesuvianite.htm)
- Kunz, George Frederick (1903), American Journal of Science, 4th. Series, Vol. 16 pp397-398 “Californite (vesuvianite); a new ornamental stone”
- Palache, Charles, Harry Berman & Clifford Frondel (1944): The System of Mineralogy of James Dwight Dana and Edward Salisbury Dana Yale University 1837-1892, Seventh edition
- Shannon, E. V. (1922) Note on the cyprine from Franklin Furnace, New Jersey. American Mineralogist, 7, 140-142.
- Introduction to Optical Mineralogy *3rd edition (2003), Prof. W.D. Nesse*

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16.70.01: Idocrase

Idocrase

Idocrase	
Chemical composition	Complex calcium aluminum silicate
Crystal system	Tetragonal
Habit	Prismatic terminated by truncated pyramids, massive, fibrous
Cleavage	Poor
Fracture	Sub-conchoidal
Hardness	6.5
Optic nature	Uniaxial +/-
Refractive index	1.700 - 1.725
Birefringence	0.005
Dispersion	Low, 0.019
Specific gravity	3.25-3.50
Lustre	Vitreous
Pleochroism	Weak to distinct (shades of body color)



Figure 16.70.1.1***:*** *Faceted idocrase*

Idocrase image gallery

Synonyms: Vesuvianite, Ambosselite
Idocrase was first discovered on Mount Vesuvius and originally named vesuvianite in 1795 by the famous mineralogist Abraham Gottlob Werner. The French mineralogist Rene Just Hauy suggested it should be named Idocrase four years later. Both names are used interchangeably. The Gemological Institute of America prefers idocrase.

Variental Names: Cyprine, Californite

Cyprine is a blue copper-containing variety of idocrase (vesuvianite) that was first described from Norway about 1821 by the famous mineralogist Berzelius; the name is derived from Cyprium, the ancient term for copper.

Californite is a compact massive form of idocrase that has an appearance to poor quality jade. It has historically been used as a jade simulant.

Crystal System

Tetragonal or monoclinic.

Crystal Habit

Prismatic to equant stubby crystals; massive granular to fine-grained.

Chemical composition

$Ca_{19}(Al,Mg)_{13}B_{0-5}(Si_2O_7)_4(SiO_4)_{10}(O,OH,F)_{10}$ often containing trace to minor amounts of iron, copper up to 2.1% (as Cu in cyprine), chromium, manganese, titanium, boron or beryllium.

Diagnostics

Recently, idocrase has been misrepresented and sold as transparent hydrogrossular garnet. It's properties can be essentially indistinguishable from hydrogrossular garnet with standard gem testing equipment, with the possible exception of the polariscope.

Peridot has a lower refractive index (1.654 to 1.670).The californite variety of vesuvianite (idocrase) floats or sinks slowly in methylene iodide; jadeite sinks (specific gravity less than 3.3). Nephrite has a lower specific gravity (3.295).

===Color=== yellow, yellowish green, green, emerald green, yellow brown, brown, blue, violet to magenta; sometimes displays distinct color zoning.

Magnification

Idocrase often shows a "heat-wave" effect similar to grossular garnet.
Under magnification, the cyprine variety may exhibit a distinctly fibrous appearance.

===Cleavage=== poor on {110}, {100} and very poor on {001}

===Specific Gravity=== 3.32 - 3.34 (measured); 3.42 (calculated)

Optical Nature

Uniaxial (+) or Uniaxial (-); biaxial idocrase has been observed. Idocrase appearing singly refractive has been observed.

Refractive Index

nω = 1.703 – 1.752 nε = 1.700 – 1.746. The variety cyprine from Franklin New Jersey demonstrates a lower range of refractive indices, with nω = 1.696 – 1.712 nε = 1.710 – 1.719.

Birefringence: approximately 0.005; it can be so extremely low (0.001), that it is often indistinguisable with standard refractometers.

The optical character of idocrase is uniaxial with mostly a negative optic sign. Hydroxyl rich gemstones may be uniaxial +.
Sometimes idocrase can be isotropic or biaxial +, in some zoned crystals the optic nature can be biaxial in some areas and uniaxial in other.

Pleochroism

Weak; nω = colorless to yellowish, nε = yellowish, greenish, brownish.

Spectroscope



Figure 16.70.1.2***:*** *Spectrum of idocrase: absorption band at 464nm.*

Treatments

None known.

Phenomenon

None known.

Synthetics

None known.

Imitations

None known.

Occurrence

See Vesuvianite.

Sources

- Deer, Howie & Zussman: An Introduction to Rock Forming Minerals
- Anthony, John W., Bideaux, Richard A., Bladh, Kenneth W., and Nichols, Monte C. (1990): Handbook of Mineralogy: Mineral Data Publishing, Tucson, Arizona
- Dietrich, R. V. (2005): “Vesuvianite” (webpage at: http://www.cst.cmich.edu/users/dietr1rv/vesuvianite.htm)
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16.70.02: Californite

Californite (variety of Vesuvianite)

The massive variety of vesuvianite is often called "Californite". This name has been given by the American mineralogist G.F. Kunz after his study about some samples coming from Happy Camp, Siskiyou County [1]. Californite coming from that area today is sometimes marketed as "Happy Camp Jade". Not being either jadeite nor nephrite the term "jade" in describing this material should be considered a misnomer and its use should not be encouraged. Being somehow similar to jade, this material is often referred to as being a "jade simulant". It's somehow a pity, since the high-grade material can be very beautiful by itself, and there is no need for any reference to other materials, even if similar. Massive vesuvianite is found also in different parts of California (e.g. Fresno County), and occasionally in some other part of the world (e.g. Russia and Switzerland).

Vesuvianite is typically found in areas that have been subjected to contact metamorphism events involving impure limestones, and its typically associated with grossular garnet. Californite from Happy Camp (and other localities) is no exception, and it's found also associated with white-ish massive grossular, serpentine, and other minerals (see many references in [2]). XRPD analysis showed that the translucent green parts of a californite sample from Happy Camp are pure vesuvianite, while the areas more opaque and lighter green in color have typically a few percent (~8% by weight in the sample analyzed) of chlorite associated (M. Voltolini 2011, pers. comm.). Massive vesuvianite is relatively easy to work, especially the high-grade material of pure vesuvianite, and can provide beautiful cabochons or other lapidary items. It's often green with some yellow/brown highlights, but other colors (e.g. white-ish, brown, etc.) are known to occur [2].

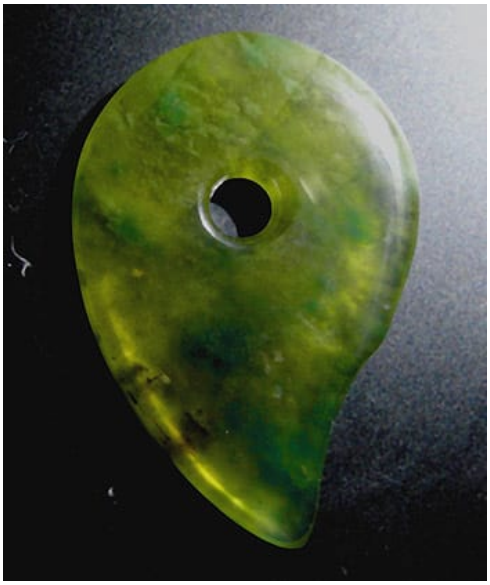


Figure 16.70.2.1***:*** *Magatama made of high grade, ~100% vesuvianite, californite from Happy Camp, CA (USA).*

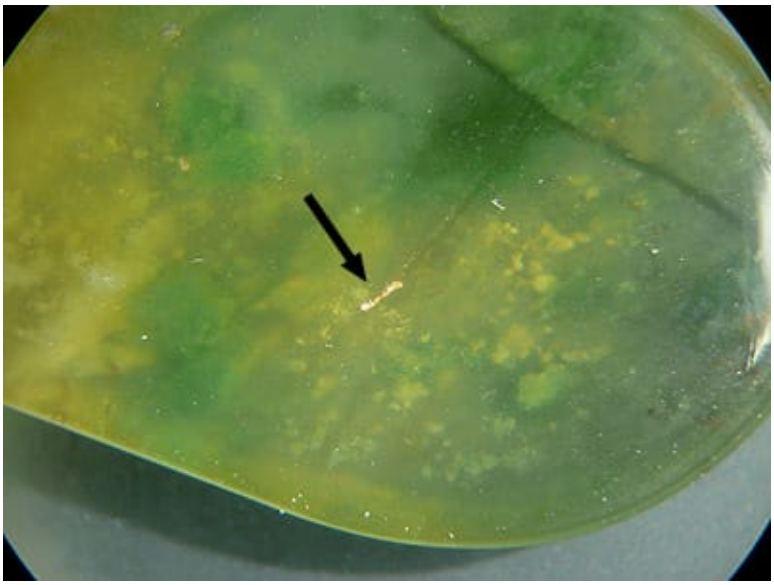


Figure 16.70.2.2***:*** *Photomicrography of a cabochon of californite from Happy Camp showing an inclusion of native gold (arrow) and the texture of the material. Tiny particles of gold are not infrequent in Happy Camp massive vesuvianite-bearing rocks.*



Figure 16.70.2.3***:*** *Californite used as a material for knife scales. The part lighter in color and more opaque (right side) is enriched in chlorite.*

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[1] G. F. Kunz. (1903) Californite (vesuvianite): a new ornamental stone. Am. Jour. Sci., 4th ser., vol. 16, pp. 397-398.
[2] J. Murdoch and R.W. Webb (1966) Minerals of California - Centennial volume (1866-1966) (Many references available, even if old. Freely downloadable at: http://www.archive.org/details/centenniamineral00murdrich)

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16.71: Willemite

Willemite

Willemite	
Chemical composition	Zn_2SiO_4
Crystal system	Trigonal
Habit	prismatic; massive
Cleavage	indistinct
Fracture	Conchoidal to irregular
Hardness	5.5
Optic nature	Uniaxial +
Refractive index	1.691 - 1.725
Birefringence	0.028
Dispersion	n d
Specific gravity	3.89 - 4.19
Lustre	Vitreous to resinous
Fluorescence	green to yellow

Willemite was named after King Willem (William) the first (1772-1843) of The Netherlands, by the French mineralogist Armand Lévy who discovered it in 1830 on former Dutch soil (present-day Belgium).

Crystal Habit

Crystals are long to short prismatic, to 10cm in length. Also fine to coarse granular massive.

Chemical Composition

Zinc silicate, Zn2Si04. Minor to trace amounts of iron, aluminum, manganese, calcium, and magnesium may be present.

Diagnostics

Yellow to yellow-green shades of willemite can be confused with golden beryl (which possesses a lower refractive index at 1.570 - 1.575, is harder at 7.5 to 8, and has a lower specific gravity of 2.72), and chrysoberyl (which is harder at 8.5, has a higher specific gravity 3.73, and a higher refractive index at 1.746 – 1.755).

Color

Transparent rough is colorless to golden yellow, pale blue-green. A canary-yellow variety of willemite from Tsumeb, Namibia has been documented, with the color attributed to cadmium (although whether the cadmium is present at a substitute for an essential component, or as finely divided greenockite – cadmium sulfide – is uncertain). Massive material cut en cabochon may be white, apple green, amethystine, yellow to golden brown, grayish, brown. An opaque flesh-red variety is called “troostite” which consists of exsolution laminae of willemite in tephroite, a manganese silicate.

Magnification

may exhibit black inclusions of franklinite, an iron manganese zinc oxide.

Specific Gravity

3.89 – 4.19, sinks in all usual heavy liquids.

Refractive Index

nω = 1.691 – 1.694 , nε = 1.719 – 1.725

Treatments

There are reports that some rough has been heat-treated to convert it from colorless to blue.

Phenomenon

The willemite from Franklin and Ogdensburg, Sussex County, New Jersey commonly fluoresces a brilliant green under Short Wave ultraviolet. It also commonly is phosphorescent, with some specimens continuing to luminesce for hours after excitation has terminated; triboluminscence (luminescence when the specimen is abraded or broken) has been observed. Willemite with a butter-yellow fluorescence has been observed but is uncommon at both Franklin and Ogdensburg. Fluorescent response in Namibian willemite appears to be more erratic in its presence or absence, and tends to be yellow under Short Wave ultraviolet radiation and yellow to orange under Long Wave. Fluorescence must not be considered diagnostic; non-fluorescent willemite has been observed. The “troostite” variety may appear as homogenous willemite in white light, but can exhibit thin lines or streaks of fluorescent green in a non-fluorescent groundmass.

Synthetics

None known.

Imitations

None known.

Occurrence

Willemite occurs as a primary and secondary mineral in metamorphosed zinc ore deposits. It is uncommon, except at the zinc mines of Franklin and Ogdensburg in Sussex County, New Jersey, where it is one of the three primary ore minerals. Enormous tonnages were mined between circa 1830 and circa 1980. In the late 19th century, one crystal recovered yielded enough rough to cut several stones; the largest faceted stone was 8 carats and became part of the Frederick A. Canfield collection. Of willemite as a gemstone, Dunn (1995) writes: “Willemite has been cut as an uncommon, exotic gem. Fine-quality gemstones have been cut from orange-yellow willemite crystals: gems of 11.1 and 11.7 carats are in the Smithsonian Institution; one of 36.93 carats is in the Harvard Mineralogical Museum; one of 6.28 carats is in the American Museum of Natural History in New York. Massive material may be quite clean internally and translucent and has provided some gemmy material for the cutting of cabochons.”Facet-grade willemite has also been recovered from the Tsumeb (Tsumcorp) Mine in Tsumeb, Namibia.

Care and Maintenance

Willemite can be decomposed by mineral acids into a colorless silica gel; care should be exercised in the use of chemical cleaning agents.

Sources

- Anthony, John W., Bideaux, Richard A., Bladh, Kenneth W., and Nichols, Monte C. (1990): Handbook of Mineralogy: Mineral Data Publishing, Tucson, Arizona
- Dunn, Pete J. (1995) Franklin and Sterling Hill, New Jersey: the world's most magnificent mineral deposits
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16.72: Zincite

Zincite

Zincite	
Chemical composition	(Zn,Mn)O
Crystal system	Hexagonal
Habit	Pyramidal (hemihedral); massive
Cleavage	Perfect on {10-10}; Parting on {0001}
Fracture	Conchoidal
Hardness	4
Optic nature	Uniaxial +
Refractive index	2.013 – 2.029
Specific gravity	5.66
Lustre	Sub-adamantine to resinous
Fluorescence	Pale yellow (extremely rare)

Habit

Pyramidal crystals, distinctly hemimorphic; massive.

Chemical composition

Zinc oxide, ZnO. Usually with minor amounts of manganese (less than 7%), and minor to trace amounts of iron, magnesium, and aluminum.

Diagnostics

Because of its high specific gravity, zincite is unlikely to be confused with any other gem material.

Color

Deep red, deep orange. Manganese is the coloring agent. Green zincite has been observed in nature but to date has not been found in sizes sufficient to facet.

Magnification

Black submetallic inclusions of franklinite or hetaerolite (both oxides containing zinc and manganese) are common.

Specific Gravity

5.66 (measured) 5.67 (calculated)

Refractive Index

$n_\varepsilon = 2.029$, $n_\omega = 2.013$

Treatments

None known.

Phenomenon

Zincite may, in extremely rare instances, display a pale yellow fluorescence in long-wave ultraviolet light. This has not yet been documented in cut stones.

Synthetics

Synthetic zincite flooded the US market in the late 1980's and 1990's, available in a rainbow of colors from pale green to green, pale red to deep red, and yellow to deep orange synthetic. This material was derived from the smokestacks of a metal refinery in Silesia, Poland, where it had crystallized over many years from volatized zinc oxide. Zincite is also grown in laboratories by several techniques, including hydrothermal, Czochralski pull, and vapor deposition (sublimation) methods.

Imitations

None reported.

Occurrence

As a primary and secondary mineral in metamorphosed zinc-iron-manganese ore deposits. Zincite is actually very rare, except at the zinc mines of Franklin and Ogdensburg in Sussex County, New Jersey, where it is one of the three primary ore minerals. Enormous tonnages were mined between circa 1830 and circa 1980.

Sources

- Anthony, John W., Bideaux, Richard A., Bladh, Kenneth W., and Nichols, Monte C. (1990): Handbook of Mineralogy: Mineral Data Publishing, Tucson, Arizona
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- Palache, C. (1935), Minerals of Franklin and Sterling Hill, New Jersey, USG Professional Paper 180
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16.73: Zircon

Zircon

Zircon	
Chemical composition	$ZrSiO_4$ Zirconium silicate
Crystal system	Tetragonal
Habit	Prismatic (squared) with pyramidal terminations
Cleavage	Poor
Hardness	7.5
Optic nature	Uniaxial + to isotropic
Refractive index	1.78 - 1.99
Birefringence	Up to 0.059
Dispersion	High, 0.039
Specific gravity	3.90-4.69
Lustre	Vitreous to sub-adamantine
Pleochroism	Weak (stronger in heat-treated)



Figure 16.73.1***:*** *Blue Zircon*
Photo courtesy of Lembeck Gems

Zircon image gallery

Zircon is a mineral species that can be broadly defined as a zirconium silicate containing trace amounts of the radioactive minerals hafnium, uranium and thorium. Over time, these radioactive components break down the lattice of the crystal, eventually (over tens of thousands of years) destroying the internal crystal lattice and leaving it with an amorphous structure and a dark, pithy appearance.
Zircons that are geologically young and unaffected by radioactivity are termed "high" zircons. These stones are transparent golden, yellowish-green and greenish-brown in color with incredibly high dispersion. "High" zircons can be heated to temperatures greater than 900 degrees Celsius, when they become colorless, blue or golden.

These highly dispersive colorless stones have long been used as diamond substitutes. That's why the name zircon has the connotation of synthetic or imitation. It was used to imitate a diamond, but the stone is indeed naturally occurring. It should not

be confused with the synthetic cubic zirconium (zirconia) or "CZ", which is laboratory-created as zirconium oxide and is in no way related to naturally occurring zircon.

Zircons in which the crystal lattice has been broken down are named "low type" zircon. These are also named "metamict" as the lattice destruction process through alpha particle decay is termed metamictization.
Zircons that are in a transitional state between high and low type are termed "intermediate" or "medium" type.

Diagnostics

One of the most typical features of zircon (high type) is the high double refraction. White zircon is almost always heat treated (from reddish-brown zircon) and this heat treatment also restores the crystal lattice to high type, so it will show clear doubling of pavilion facets in faceted stones when viewed through the crown.
As white zircon may mimic a diamond, the "dot test" is a very valuable one. Zircon is the only strong doubly refractive diamond simulant that has a refractive index lower than diamond, but is still over the limit of a gemological refractometer.

Color

- High and intermediate type zircon:

  Colorless, blue, yellow, yellow-green, brownish-green, orangy-brown to orangy-red, pink and purple.

- Low type zircon:

  Cloudy brownish-green and yellowish-green (sometimes orange or brown).

Spectroscope

Zircons (especially high type green and yellow ones) show a typical uranium spectrum with up to 40 lines. The most diagnostic line will be at 653.5 nm
However, some zircons, like metamict type or heat-treated white and blue ones, may show only a faint line at 653.5 nm. The red-browns from New South Wales, Australia and Cambodia may not show a spectrum at all.

Heat treatment of metamict zircon tends to sharpen the faint absorption lines.

Chelsea Colour Filter

Blue zircons have a green reaction under the CCF. Orange-browns ("hyacinth") will show up orange-red.

Polariscope

Only 2 of the most common, natural, gemstones are uniaxial with a positive optic sign, zircon and quartz (phenakite, cinnabar and some idocrase are also uniaxial +, aswell is synthetic moissanite).
Quartz will usually show a bull's-eye (or quadruple Ariry Spirals), so if you find a positive optic sign on a typical uniaxial interference figure you might suspect zircon. Of course, you will need a retardation plate to determine the optic sign.

It should be noted that, due to metamictization, some zircons will not show an interference figure and these stones remain dark on rotation between crossed polars.

Magnification

Zircon is brittle and may show abrasion on facet edges. When sending out lots of zircon, be sure to wrap each stone individually to prevent this "paper wearing" effect.

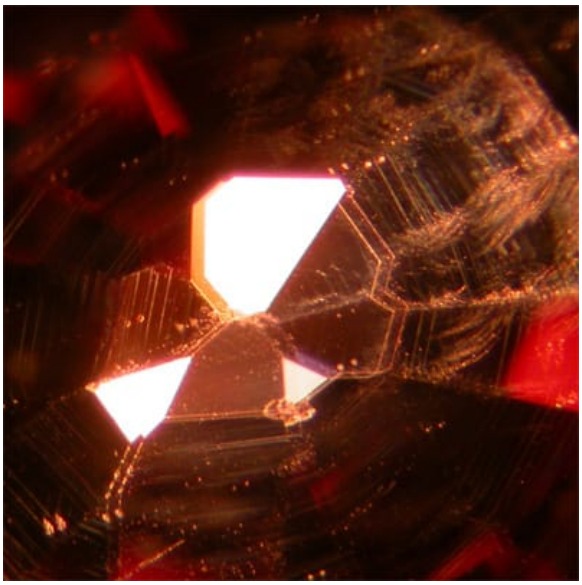


Figure 16.73.2***:*** *Distinct and diagnostic doubling of back facets, polishing lines and inclusions*
20X Magnification
by Barbra Voltaire

Fluorescence

Zircons may fluoresce mustard-yellow in varying degrees (sometimes inert) under long and shortwave UV light.
When heat treated zircon is exposed to this kind of radiation for a prolonged amount of time, the color may reverse back to the color prior to heating (a not so favorable result).

Treatments

Zircon is routinely heat treated. This heat treatment has two effects on the gem:

1. It alters the color to colorless, blue or golden (the most preferred colors for zircon) and orange to red colors.
2. The crystal lattice of metamict zircons is restored to high type zircon.

Heat treatments are carried out in either an oxidizing or a reducing atmosphere (or a sequential combination).

- Orangy-brown to reddish-brown zircons ("hyacinth") are heated at around 900° C in an oxidizing atmosphere which turns them yellow to red.
- Or when these brownish zircons are heated at around 1000-1400° C in a reducing environment, it turns them into colorless or blue. Some off-colors are the result of this process as well.
- These off-colored stones, from the reducing treatment, are then reheated to around 900° C in oxidizing conditions and this results in colorless, yellow, orange or red colors.

Although colorless, blue and red zircon does exist in nature, they are very rare and there are no known means available to distinguish between them and their heated counterparts.

Zircon to calculate the age of the earth

Zircon forms in granites deep in the earth's crust (plutonic rock). Through movement of tectonic plates, this granite is brought to the surface and starts mountain building. Through erosion, the granite (and the contained zircon) builds sediments which will eventually be buried deep enough to transform into metamorphic rocks.

Zircon has two important properties:

1. Relative high hardness
2. Resistance to chemical attacks

Due to its hardness of 7.5 on the scale of Mohs, the zircons usually survive the sedimentary process intact. Because of its resistance to chemical attacks, zircon will survive the contact metamorphism process which is trying to attack it with heat and pressure. The latter is important as the liquid mass surrounding the zircon will cause a new rim to be formed around the old zircon, just like the formation of tree rings. This first cycle usually will take hundreds of million years.

The old crystal with its newly formed rim is then pushed up again through tectonic plate interactions, then this geologic cycle repeats itself.

A third and well-known property of zircon is that it can accommodate radioactive elements like uranium. Uranium has the ability to decay into lead at a fixed time rate. Calculation of the uranium-lead ratio may give a clue of the age of the zircon (and thus Earth's age). However, lead may leak from the zircon, disturbing the uranium-lead ratio.

Fortunately, scientists found a new way of calculation by using isotopes. The uranium-238 isotope (with a half-life of 4.468 billion years) decays to lead-206, while uranium-235 (with a half-life of 703.8 million years) decays to lead-207. The "secondary ion mass spectrometry" (or SIMS) technique is used for this kind of measurement. By measuring both 'parent-daughter' decays of both these processes, an accurate age of the zircon can be calculated -- that is if both measurements are consistent (which is not always the case).

The Isua rocks on Greenland are a source for this way of dating the earth's age. Current calculations indicate Earth is 4.6 billion years old.

Sources

- *Gemstone Enhancement* (1984) - Kurt Nassau ISBN 0408014474
- Gems Their Sources, Descriptions and Identification *4th Edition (1990) - Robert Webster (6th ed.)*
- *Gem Reference Guide* (1995) - GIA ISBN 0873110196

External links

- A birthstone for earth

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17: LAPIDARY ARTS

17.1: Lapidary Arts
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17.1: Lapidary Arts

Lapidary Arts

This section has been created in order to allow gemology students, novice cutters and other rock-folk to have a peek in the kitchen of the lapidary artist. The section features general information on cabbing, faceting and carving as well as equipment descriptions, tutorials, and a faceting design database.



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17.2: Faceting

Faceting

Basics of Faceting

Introduction

In the gemological terms, facets are small polished planes arranged in a geometric pattern on a gemstone. Faceting is an art of cutting a faceted gemstone. It can be roughly divided into two aspects:

1. Shaping - How facets are placed on a gemstone, and how a rough stone is cut into a certain shape.
2. Polishing – After a stone is shaped, how facets are polished.

In this tutorial, these procedures are explained as well as a brief description of a faceting machine and a diagram.

Faceting Machine

Each facet is cut by grinding a rough stone on a flat round file called a lap. The lap turns around horizontally in a faceting machine. Usually water, oil or WD40 is used on the lap as a coolant/lubricant. The rough stone is adhered to a small stick called a dop. It is seated in the quill in a faceting head. The faceting head allows the dop and rough stone to swing horizontally at a set angle.



Figure 17.2.1

The image above is an example of a faceting machine. The gray disc on the lower-left corner is a lap. This picture shows a dop with a rough stone in the quill.

There are only three factors to place a facet:

1. what angle to the dop to cut,
2. which side of the stone to cut, and
3. how much to cut off.

A faceting machine precisely controls these three factors with the faceting head. The angle control/protractor can be set the dop at certain angles. The index can rotate the quill and orient the stone to certain sides. The mast height controls how much to cut off.

Diagram

Diagrams are blueprints of gemstone designs. They tell us to cut a rough stone at what angles on what indexes. However, a diagram does not show any direction as to how much to cut off. The individual faceter must decide how much to cut off. It depends on the design and the shape of the rough.

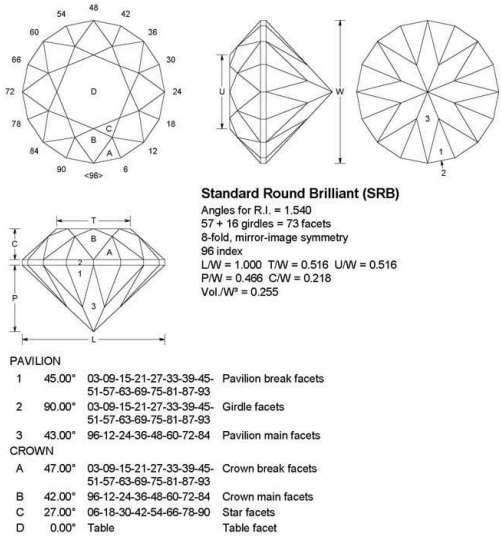


Figure 17.2.2***:*** *This is a diagram of the standard round brilliant cut. Reference: www.usfacetersguild.org/index_designs*

Shaping

To give you an idea of the steps a faceter has to follow, we are going to cut a round brilliant according to the design above. The material is dark red garnet. The diagram starts with the pavilion break facets. Let us set the angle control at 45 degrees and the index on 3. Adjust the mast height so the rough stone barely touches the lap. Grind little by little by sweeping the rough on the lap by hand. When the side on the index 3 is done, move to the index 51. Then move to 27and 75 and so on. Note that the diagram indicates the 96 index, and the interval of index numbers is 6. This means 16 equal facets are cut in a cone shape (96/6 = 16). When you finish cutting all around the rough at the same mast height, lower the mast height a little. Repeat this procedure until the rough looks like a cone. Check the progress with a 10 x jeweler's loupe. All the facets should evenly come to a center point.



Figure 17.2.3***:*** *The pavilion break facets. Notice a large pit. This pit has to be removed by grinding all the facets a bit more.*

To cut the girdle, set the angle control at 90 degrees. Note that 90 degrees in the diagram means the dop is parallel to the lap. When you cut the table facet later on, you will see 0 degree in the diagram means the dop is perpendicular to the lap. The facet angles are always between 0 and 90 degrees. Adjust the index to one of the index numbers on the girdle facets in the diagram. Cut all around the rough until it forms a 16-sided short cylinder. This part will be the girdle and crown.



Figure 17.2.4***:*** *The 16-sided short cylinder will be the future girdle and crown.*

To place the pavilion main facets, set the angle control at 43 degrees and the index to 96. Bring the mast height so the rough stone barely touches the lap. Cut on the indexes 96-12-24-36-48-60-72-84. Note the interval is 12, which means you are cutting 8 equal facets instead of 16 (96/12 = 8). Lower the mast height little by little. Take a careful look at the pavilion figure of the diagram. Cut until the main facet tips meet the girdle as the figure shows. Take care not to overcut or undercut.

At this point, the pavilion facets and girdle need to be polished. These procedures will be described later in the Polishing section below.



Figure 17.2.5***:*** *The pavilion and future girdle are shaped and polished.*

To cut the crown facets, the stone needs to be transferred from the original dop to another dop on the exactly opposite side. For this stone, we use a cone dop. The cone dop accommodates the tip of the pavilion on a transfer block. Now you have the stone that has two dops on both sides. Remove the original dop by an appropriate method. Now the stone is transferred.



Figure 17.2.6***:*** *The stone with two dops is on a transfer block.*

To shape the crown, let us start with the crown break facets. Seat the cone dop in the quill of the faceting head. Set the angle control at 47 degrees and the index on 3. Adjust the mast height so the stone touches the lap. Cut all the girdle facets until the girdle is approximately 0.5-1 mm wide. The girdle width should be proportional to the size of the stone.



Figure 17.2.7***:*** *Beginning of cutting the break facets. Notice that the break facets don't align perfectly with the girdle. This is not uncommon. There is an index micro-adjuster called a cheater on the machine. Use the cheater to correct the alignment.*

Let us move on to the crown main facets. Set the angle at 42 degrees and the index to 96. Adjust the mast height so the stone barely touches the lap. Cut on the indexes 96-12-24-36-48-60-72-84. Note the interval is 12, which means you are cutting 8 equal facets. Cut until the tips of these facets meet the girdle.



Figure 17.2.8***:*** *The crown main facets*

Next we are going to cut the star facets. Set the angle control at 27 degrees and the index to 6. Adjust the mast height so the stone barely touches the lap. Cut on the indexes 6-18-30-42-54-66-78-90. The intervals are 12, but this time you are cutting the new facets in a staggered manner. Cut until the tips of the star facets meet the break and main facets.

At this point, the crown facets need to be polished. These procedures will be described later in the Polishing section below.



Figure 17.2.9***:*** *After cutting the star facets, the entire crown is polished.*

The diagram shows the angle of the table facet is 0 degree. The dop has to be positioned perpendicular to the lap. It can be done with a 45-degree table block. Set the angle control at 45 degrees. Engage the table block to the quill. Seat the dop in the table block. Cut the table by sweeping the stone.



Figure 17.2.10***:*** *The dop is positioned perpendicular to the lap with the table block.*

Finally the table facet needs to be polished. These procedures will be described in the Polishing section.



Figure 17.2.11***:*** *This is the finished stone. In the same way, you can facet a stone into any design by following a well-written diagram.*

Polishing

You may have noticed that there is no directions as to what laps to use for shaping, or what agents to use for polishing in the diagram. The individual faceter must establish his/her own methods empirically, or based on information available from faceting classes, personal communication, publications, the internet etc. That is one of the reasons why faceting is considered an art.

The following pictures show a sequence of a crown being cut and polished at various stages. The material is YAG. It is an example to give you an idea how polishing goes. Faceters may use other methods and still obtain the same results.

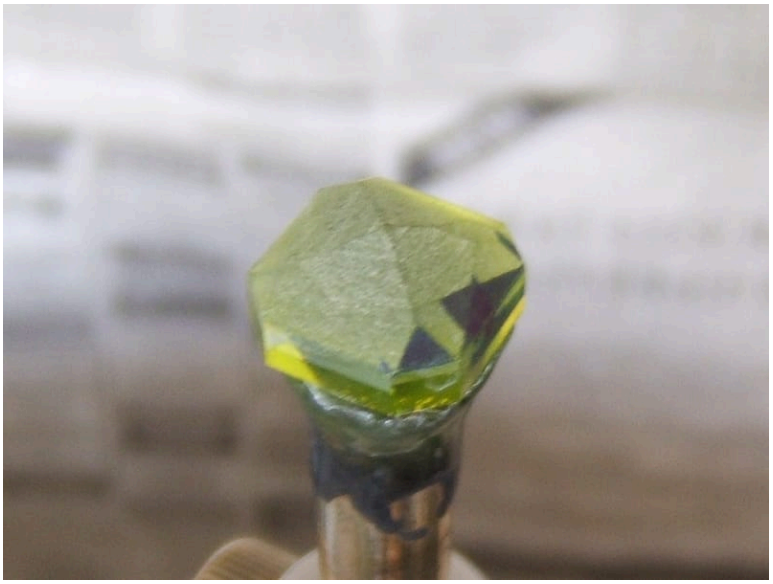


Figure 17.2.12

For this particular stone, the pavilion and girdle have been already shaped and polished. The stone has been transferred to a cone dop. Since this is a large stone the bulk of the rough is removed with a coarse 260-grit lap. At this stage, pay attention to the alignment of the break facets to the girdle facets, i.e., cheating. Notice the wide girdle. Stop using the coarse lap when the girdle is 3-4 mm wide.



Figure 17.2.13

The crown is shaped on a 600-grit lap as explained in the Shaping section. Continue on cheating, and start paying attention to the meet points.



Figure 17.2.14

The crown facets are pre-polished on a tin alloy lap charged with 3,000-grit diamond. Pre-polishing goes through the same sequence using the same angles and index numbers in the diagram. Good pre-polish makes each facet surface ready to be polished. This stone shows a smooth, almost finished appearance.



Figure 17.2.15

Each facet is polished on a composite lap charged with aluminum oxide. Check the facet surface with a 10 x jeweler's loupe to see if there is any scratch left on the facets. Polish the facets until they are completely smooth like a mirror. Polishing repeats the same faceting sequence in the diagram.



Figure 17.2.16

This is the finished stone off the dop and cleaned.

There are several choices of polishing methods depending on the types of stone. Most commonly used agents are fine grit diamond (50,000-grit or 100,000-grit) and oxides such as cerium oxide and aluminum oxide. They are used on a tin alloy lap or a composite lap.

Besides shaping and polishing, there are many more aspects on faceting. They include how to prepare and orient a rough stone, how to dop the rough stone, what adhesives to use for dopping, how to transfer the stone, and which laps to use at various stages for various stones etc. They are beyond the scope of this tutorial. You may find the information in the discussions on the GemologyOnline Forum or elsewhere.

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17.3: Easy Combination Cutting MV

Easy Combination cutting MV

Combination cutting: a minimalist approach - Marco Voltolini

With the term "combination cutting" we basically mean those cuts where faceting and carving techniques are combined by the lapidarist.

In this tutorial, I'll show how to cut such a stone with minimal equipment (assuming you already have a faceting machine). Improved and more specialized equipment is of course used by the real pro's in the field. Anyway even with my simple approach it is possible to obtain very good results: I'll show you how I cut an aquamarine featuring "bubbles", "channels" and other features, to obtain a cut stone truly different from what you can usually find on the market.



Figure 17.3.1***:*** *Aquamarine rough used for this tutorial*

Let's start with the rough: in my case it's an aquamarine. The piece is rather flat and has a couple of small surface cracks. Now, with combination cutting the depth required to cut a stone can be smaller that the one required by conventional facet designs, because it is usually not a problem to have open culets and/or carve that part of the stone. So combination cuts can offer a bonus when you have a nice, clean, big, but flat piece of rough. Also, surface flaws are not an issue: you can plan a "bubble" (or any other carved feature) strategically, in the position where those flaws are. I would suggest to use only clean pieces, since evident flaws can detract the attention from the carved features (unless you are dealing with some nice-looking included materials, tourmalinated quartz, for example)

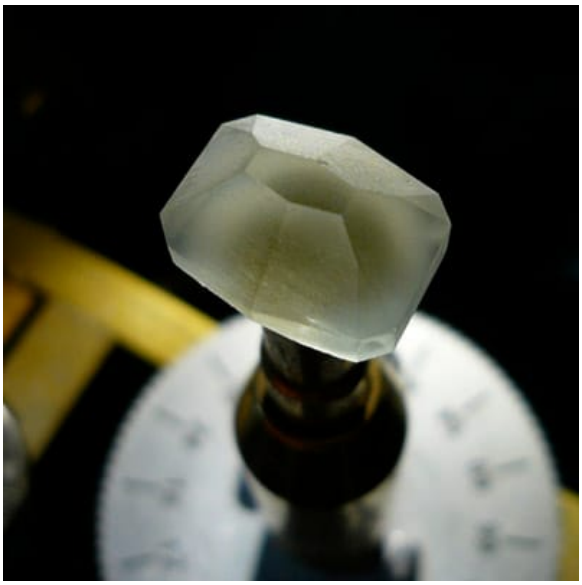


Figure 17.3.2***:*** *Cutting the preform*

Once you have selected your piece of rough, just dop it and start to facet the stone. Any design with few large facets should work well. If you want to have reflection (my advice is to do so) cut above the critical angle. I chose a cushion-ish shape and I cut all the pavilion facets at 42 degrees. I also cut a open culet. Don't waste your time cutting with fine grits here, since you'll have to recut the stone after carving. A finish using a 600 (or my very worn 260) plated lap is usually fine here. Look at the picture of my stone, where I've just finished this preforming stage.



Figure 17.3.3***:*** *Tools for carving*

Now it's time to cut the carved features on the pavilion. I quickly draw an outline on the stone using a marker. What I used at this stage:

- Dremel tool: you need such a tool (or better) for carving. A flex shaft sure will help, but mine was broken during this experiment. Using the Dermel alone is no big deal, just it's a little more uncomfortable for your wrist...

- Diamond carving burrs: I use either 600 or 1200 grit plated burrs. They can be found very cheap, but the quality is cheap as well. Anyway once you find what kind of burrs you use the most, you can upgrade those to good quality sintered burrs. Here I'm using cheap 600 grit plated burrs: a ball and a cylinder shaped ones.

- Bamboo skewers: for the sanding and polishing processes. The diameter of the skewer has to be compatible with the collet of your carving tool (i.e. ~ the same diameter of the shaft of your plated burrs).

- File for metal: if you want to shape your bamboo skewer tools. For example if you need a cone point, you just mount a piece of your skewer on the Dremel, you turn it on, and rub it at a proper angle on the file. Done. Usually the bamboo skewer will take the shape of the feature you are working into, so often this shaping process is unnecessary (es. I never do that when sanding/ polishing "bubbles"). This file will be needed when you need to do some more "advanced" tools, such as small cutting disks out of nailheads (this kind of tools have not been used on this stone).

- Oil and water to use a s a lubricant. I use olive oil for diamonds and water for oxides. But when I cut with the plated burrs I use water.

- Diamond paste (I use 600, 1200, 3000 grit), Ce-oxide (since I'm cutting beryl)

- An old toothbrush is very helpful when cleaning the stone between different diamond grits. I use a disposable surface (old newspapers, old envelopes, etc) to work onto. Toilet paper for cleaning.

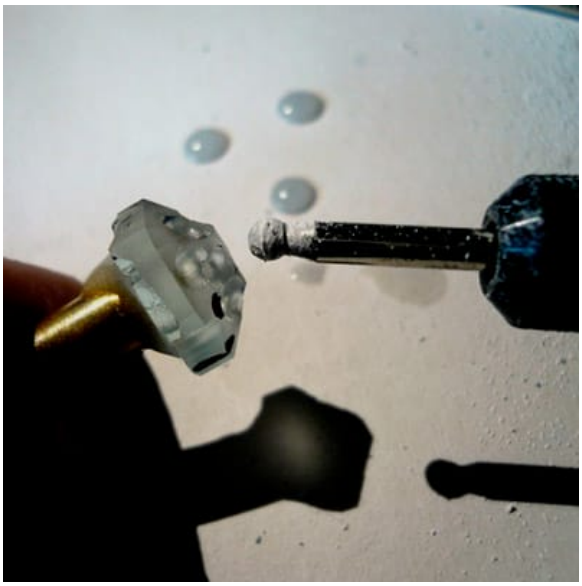


Figure 17.3.4***:*** *Plated diamond burr*

Now I use my plated burrs for carving the bubbles (ball) and the channels (cylinder). Be careful when you start cutting each feature not to slip with the burr. While cutting move the burr to avoid deep scratches: use an orbital motion for the bubbles and go forward-and-behind rather quickly when cutting the channels when you finish cutting them. Also, since you'll have to recut the stone after carving, go a little deeper than the outcome you have in mind. Pay attention not to chip too much the overlapped parts of the different carved features.



Figure 17.3.5***:*** *(pre-)Carved pavilion*

This picture is to see how my stone is after this first rough carving. Note the chipping where the bubbles meet the faceted surface. We will get rid of all those chips by recutting the stone, after finishing the carved features.

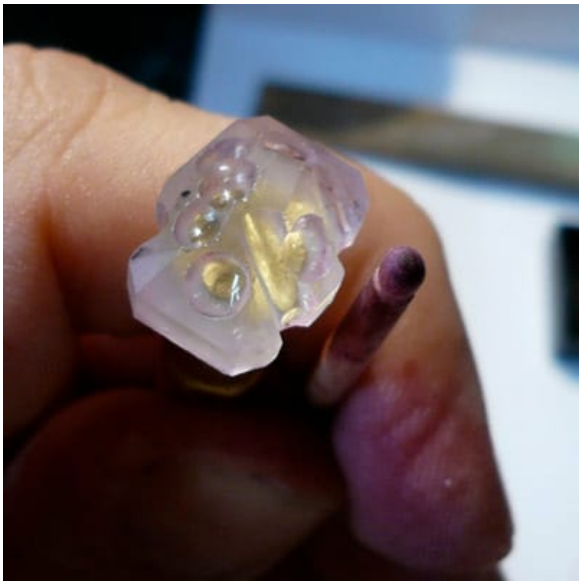


Figure 17.3.6***:*** *Sanding stage*

Next we need sanding. I started using my 600 grit diamond paste (using a hint of oil when needed). At this stage we need to smooth out all the scratches caused by cutting and to get rid of the chips where the different carved features are overlapping. There's no real need to smooth out the chips on the facets perfectly. Use the 1200 paste to smooth out the 600 grit surface. Clean again with the toothbrush. Pre-polish with the 3000 diamond paste.

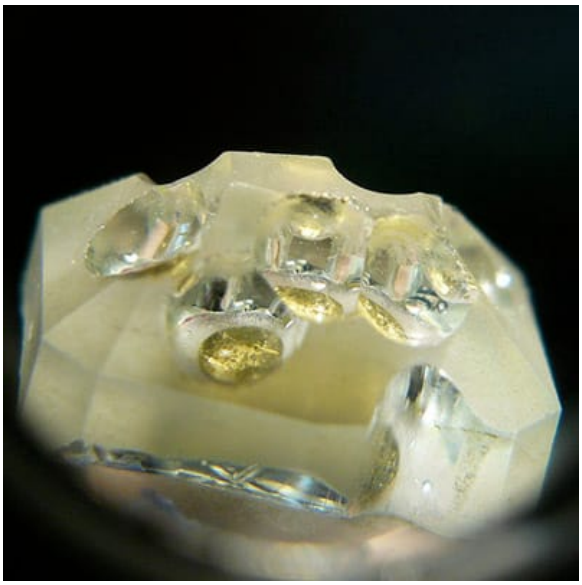


Figure 17.3.7***:*** *The carved features polished*

For polishing I use a paste made of ceria and water, and I use again a piece of bamboo skewer. At this point it's rater easy to go dry and burn the wooden tool and overheat the stone. If things are getting dry and you feel your stone getting hot, stop immediately, wait a little (do NOT wet the stone to cool it down while it has a portion still hot: it could crack), and use more water/paste. Overheating is a problem since it will consume your tool and may cause cracking in your stone. So try to avoid it as much as you can; wet your stone frequently. Notice how the carved features are well-polished, the facet-bubble junctions still have chipping, but the bubble overlaps have been sanded to obtain crisp and sharp arcs, without any chipping left.

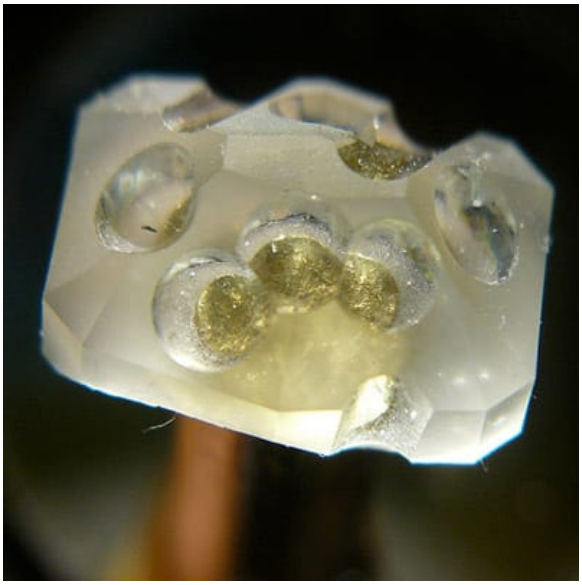


Figure 17.3.8***:*** *The carved features polished*

I have then remounted the stone on the quill of my faceting machine and re-cut the stone with my plated 600 grit lap until I got rid of all the chips. Note how crisp are now those junctions.



Figure 17.3.9***:*** *The finished pavilion*

After you got rid of all the chipping, simply proceed as usual for flat faceting: pre-polish and polish the facets. On this stone I left the culet and the girdle unpolished.



Figure 17.3.10***:*** *Cutting the crown*

Then you have to cut the crown. There are many options available: faceted crown, buff-top, mixed, etc. In this case I decided to cut a simple step crown, leaving one step unpolished to create a "frame" effect. That, coupled with the pavilion facets and the shape of the culet, adds a further impression of "depth" in the stone to the viewer. In the figure I'm starting to cut the table, using my 45 deg adapter.



Figure 17.3.11***:*** *The finished stone*

The stone off the dop and cleaned. It's pretty impressive for a stone cut using bamboo skewers, isn't it? My first stone of this kind sure wasn't as nice as this one, but with some practice the results will improve steadily. As you have seen, cutting this one was quite a lot of work, but results have been rewarding.

Different concepts & ideas



Figure 17.3.12***:*** *The tool made from a steel nailhead, mounted on a flex shaft.*



Figure 17.3.13***:*** *The finished stone: the grooves were cut using the tool on the left.*

Different carved features need different tools: in the example above we have seen how ball plated burrs can be used for "bubbles" and cylindrical burrs can be used for ~hemicylindrical grooves. For small "V" shaped grooves we can make the tool on your own out of a big iron (or, better, copper, if you can find it) nail. To make the tool in figure I simply cut the nail, mounted the end with the head on my Dremel tool, and shaped it on my file for metals. Once you have shaped it, you can charge this tool with diamond paste and use it for cutting the stone (I use 600 grit). For sanding and polishing, I used tools made from bamboo again. Using simple items available from any hardware store, it is possible to make a wide range of carving tools [1]



Figure 17.3.14***:*** *No flat facets for this one*

You don't necessarily need a faceting machine for this kind of cuts: this one features only curved surfaces (the "pavilion" is shaped like a boat) and a buff-top. "Bubbles have been carved on the "pavilion" to obtain this overall pleasing effect.



Figure 17.3.15***:*** *Lime citrine quartz. Here the crown was cabbed as a low dome, then a big flat table was cut*

Of course it is possible to mix a variety of techniques: in this stone the pavilion is flat faceted and some "bubbles" have been carved. The crown is a buff-top with a very large table. Also in this case the overall effect is pleasant to the eye.

[1] Michael Dyber (2005) Lapidary Journal, August issue. Pp. 61-67.

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