SPECIAL EDITION

Useful Crystallography

By Dave Woolley

Mineral and gem identifications are processes of elimination. Early-on we learn about color, luster, hardness, cleavage, and familiar shapes. The study of crystals seems beyond the reach of many, but the important stuff it is not difficult or expensive. A Polariscope and a Dichroscope can help in identifications with an understanding of *Useful Crystallography*. Get an old pair of gray Polarized sun glasses. Take the two lenses out and look through both at a distant light bulb. Rotate one lens until the overlapping lenses darkens. Your two lenses are now "Cross Polarized". The goal now is to mount both lens in that orientation with a small gap in between where you will hold and rotate your transparent mineral or gem. I use a small piece of wood with two notches cut to accept the two lenses. Glue them in. I use Silicon glue but be sure that lenses remain Crossed Polarized. You now have $100 Polariscope for your mineral identification and faceting tool box. This article is geared toward transparent gems but the science applies to all minerals.

Check out my impromptu talk on Crystallography given at Easter Island, store: currently the video is posted at: https://youtube.com/channel/UCrOm2CQnPCLV8FtSKWHuJCw. Scroll through their videos to find it. Thanks to Mary McIntire for running the camera and Bob for posting. It will also be found, scrolling through the videos of the Lynchburg Gem and Mineral Society web page: https://www.lynchburgrockclub.org/ You may have to become a member to access. Minerals of the different Crystal Systems can take on many *forms,* be distorted, broken, or faceted. For example, towards the end of the talk, I show a number of Cubic Crystal System minerals that have different *forms*: cube, octahedron, pyritohedron, and dodecahedron. Other minerals have typical as well as unusual *forms.*

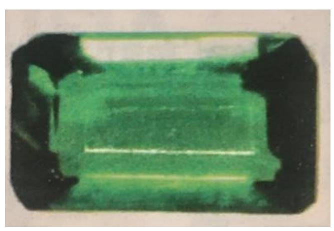
<u>You can ignore *forms*</u>*.* The “Pickup Stick” models of the video define the *interior* of the Crystal Systems. The lengths of the colored axes of the crystal models represent the Refractive Index number: the longer the axis the higher the Refractive Index number being represented. The red equal-length “A” axes of the Cubic System demonstrate the single Refractive Index of Cubic minerals, that can be viewed in any orientation. All red is Cubic. The red and yellow models are Tetragonal, Hexagonal and the related Trigonal. Blue, Green and Black models are Orthorhombic, Monoclinic (one inclined axis), and Triclinic (three inclined axes) Crystal System representations.

Quartz is a Trigonal Crystal System Mineral, often found in a six-sided *form*. You can locate the "C" axis by spotting an orientation where the stone remained uniformly dark while rotating a transparent crystal fragment or gem between Crossed Polarized filters. This is the same as looking through an unstressed Cubic Crystal System Mineral or piece of unstressed glass - in any orientation.

In other orientations Quartz (and stressed Cubic minerals and glass) gets lighter and darker in "flowing bands" as the stone is rotated. In Hexagonal, Trigonal, and Tetragonal crystals, looking down the Yellow "C" axis shows the red "A" axes, just like any orientation of the Cubic. The length of the Yellow axis can be either longer or shorter showing a greater or smaller Refractive Index than the red "A" axes. A longer "C" axis mineral is called "Uniaxial Positive" [like a positive sign (+)]. the shorter "C" axis minerals are "Uniaxial Negative" [like a negative sign (-)]. **In Hexagonal, Trigonal, and Tetragonal Crystal Systems, "Uniaxial" refers to having one "Optic Axis"** ***that coincide*****s with the "C" Crystallographic Axes.** ***An Optic Axis always present a plane of equal length axes at a right angle to the Optic Axis, similar to any view of the "A" axes view of Cubic mineral.***

Uniaxial minerals are Dichroic, that is, possibly having two different color orientations viewed near or down their two types of Crystallographic Axes. A richer color can often be selected by choosing one or the other of the orientations. Locating the "C" and "A" Axes and knowing which of the Crystallographic Axes has the greater Refractive Index allows the faceter a choice to cut a more sparkly gem. The higher the Refractive Index, the more the sparkle and fire of rainbow colors.

An unwanted color can sometimes be eliminated by choosing certain Pavilion facet angles. For example, tourmaline crystals are often faceted in weight saving rectangular "emerald cut" designs. The black "C" Axis of certain "closed tourmalines" are a problem. The otherwise dark color can be caused to leak out the bottom rather than be reflected, thus creating a perfect gem from in imperfect piece of rough.



Poorly cut black "C" axis Tourmaline. With modified *end* Pavilion angles, the black facets disappear.

This Amethyst and Aquamarine were cut for maximum size and weight, (cash value). There was no regard for the lack of beauty caused by incorrect Pavilion angles, often accepted by a consumer's ignorance. In poorly cut gems, light leaks through and from the back rather than being reflected back from the top.

A gem cut with proper Pavilion angles for maximum reflectance or sparkle, flashes of refracted color, and beauty. Well-cut gems take advantage of useful crystallography.

In Orthorhombic, Monoclinic and Triclinic minerals there are two such “Optic Axes” like looking at any orientation of a Cubic Mineral, or down the “C” Axis in Tetragonal, Hexagonal or Trigonal crystals, hence the name “Biaxial”. ***Unlike Uniaxial minerals the two “Optic Axes” of Biaxial minerals do not coincide with crystallographic axes.*** With a Polariscope or Petrographic Microscope the two Optic Axes can be located. In these minerals there are three Refractive Indexes; the intermediate Index is often overlooked in weak literature. The *one* – Cubic, or the *two* – Uniaxial, or *two of three* Refractive Indices of Biaxal minerals are sufficient to identify most gems and many minerals. With the *proper* use of a Refractometer or Petrographic Microscope, three Refractive Index of Biaxal minerals can be determined.

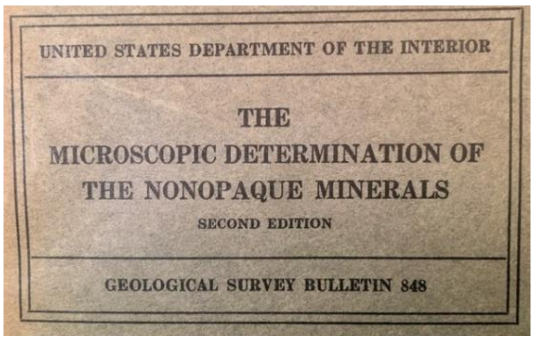
Biaxial minerals can have up to three noticeable colors – Trichroic. One is associated with the “Optic Axes”. Some gems are enhanced by using facet designs to emphasize one color; some to mix two favorable colors like the pink and purple of Kunzite. The blue and purple of Tanzanite is another example. The mineral Zoisite is Trichroic often including yellow yielding a muddy mix of colors. Heat treatment removes the un-wanted yellow with blue and purple Zoisite creating the gem Tanzanite.

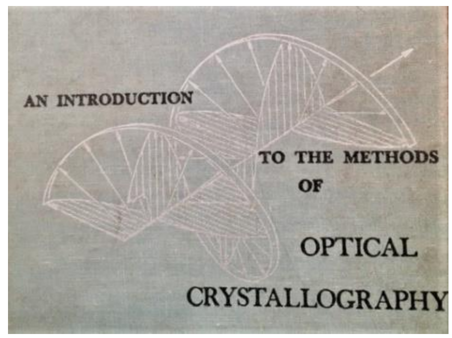
A Dichroscope can be made from two small pieces of gray Polarized sunglasses, a tube with an end blocked with a two small square cut in the end - each square with a filter turned at right angle to the other. Useful, but not essential is a magnifying lens located at the other end at its focal length away from the filters, and a roll of black paper inside the tube to absorb stay light. Earlier designs used a calcite fragment and one square window that appears twice. See: Calcite, below. A Dichroscope can be used to find the two colors of Uniaxial minerals and up to three colors of Biaxial minerals, a help for identifications. One color suggests a mineral may be Cubic. Two discovered colors suggest a mineral may be Dichroic or Trichroic. Three colors prove a mineral is Trichroic. You now have a $100 Dichroscope for the tool box.

At the end of the video, I show two cleavage fragments of Calcite. One I cleaved with equal length sides; it has a Hexagonal outline. The other has the more expected Rhombohedral shape. I polished two windows on the first; the bottom window is resting on a piece of paper that has one black dot. Only one dot is seen looking down through the top polished window because you are looking down the “Optic Axis”. The other sample is also resting on a single black dot. Looking through cleavage windows of a Rhombohedral fragment, two dots are seen. Any orientation of a none Cubic mineral that does not coincide with an “Optic Axis” causes light to be split into two paths. They are plane Polarized at 90 degrees to each other. In the Calcite examples the single dot is influenced by the “A” Axes and remains stationary when the crystal fragment is rotated. In the Rhombohedral sample the second dot is influenced by the “Optic Axis” ray path and it rotates around the stationary “A” Axes dot.

The non-moving ray path is called "Ordinary" in the literature (sometimes labeled with the letter "O" or the Greek symbol Omega); the moving-dot ray path is called the "Extraordinary". (the letter "E" or the Greek Epsilon). Being plane Polarized, one or the other dot can be eliminated, when viewed with a Polarizing filter.

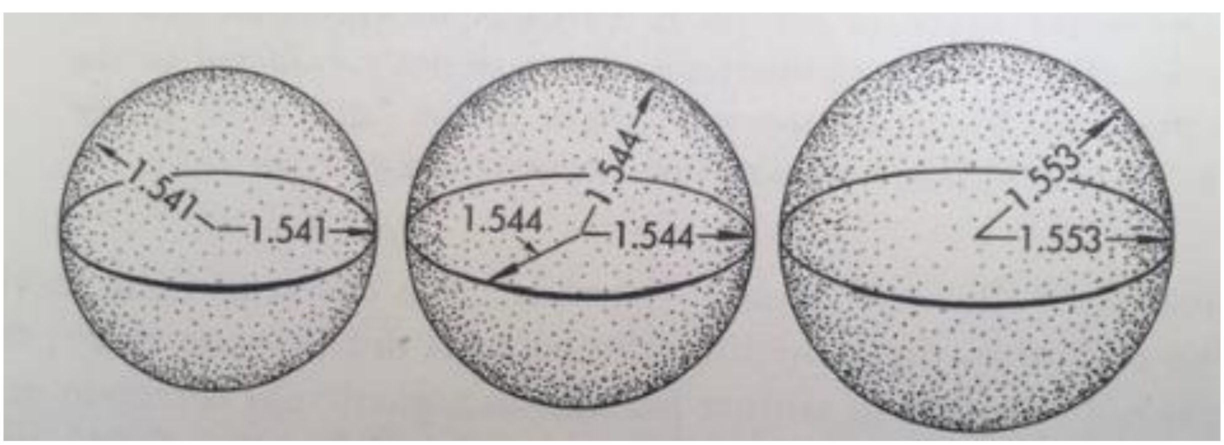
Why is this important? These optical phenomena can be examined in detail with a Petrographic Microscope, the strongest tool for mineral identification of the 19th and 20th centuries. With this device the Cleavage, Specific Gravity, Refractive Indexes, Crystal System, Crystallographic and Optic Axes and much more can be determined in crystals trapped within a thin slice of rock, or of crushed grains of an unknown mineral. Unknown minerals can be named with references like these:

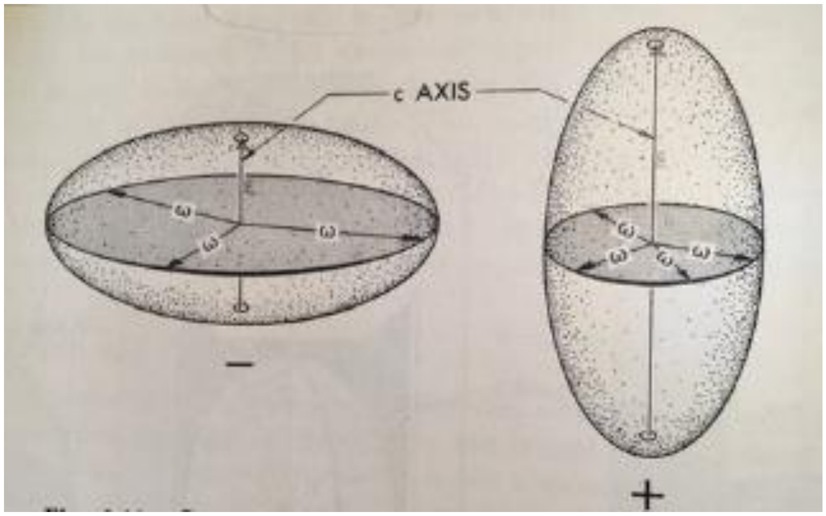




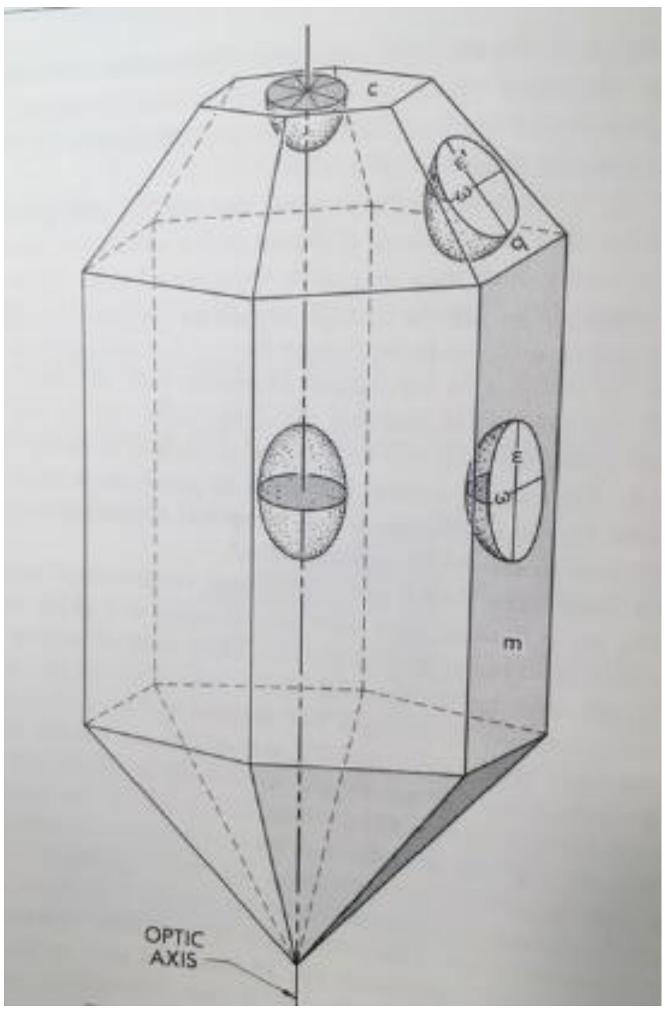
A sample may be a cut gem, a fragment, or have a recognizable crystal shape. Let's now put some flesh on the bones of the crystal models. At this stage of understanding, the concept of an "Indicatrix" is helpful in *visualizing the interior.* The size and shape of an "Indicatrix" is determined by the Refractive Indices (length of the axes), the angular relationships of the axes, and the location of Optic Axes, if any. Cubic minerals can be pictured as a sphere; the three equal axes touch the interior of a round shape. Comparatively, a smaller diameter sphere has the lower Refractive Index. Note that a Cubic Indicatrix has an infinite number of "Circular Sections" viewed in any orientation.

The following sketches are taken from "An Introduction to the Methods of Optical Crystallography" by F. Donald Bloss, 1976, Holt, Rinehart and Winston.



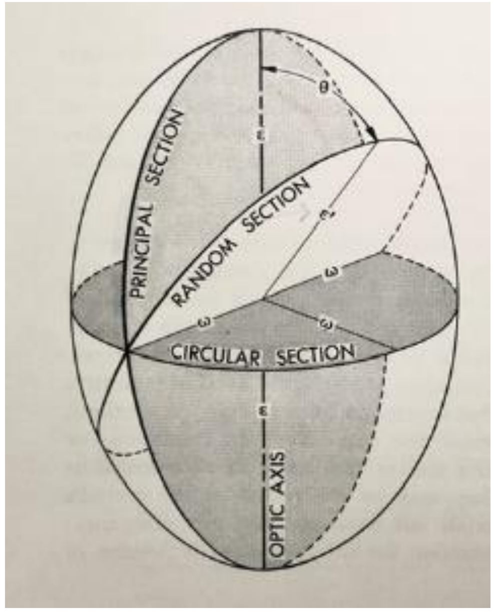


Uniaxial negative and positive Indicatrix



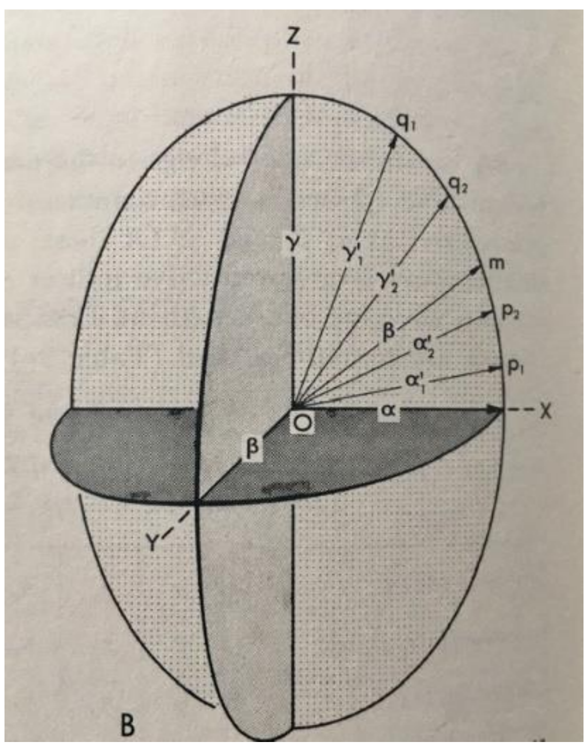
A Quartz crystal (Uniaxel Positive) with its Indicatirx pictured in the center. The labeled “Optic Axis” is the same as the “C” Axis in the Trigonal crystal systems. Look down the “Optic Axis” from the top. There is an error in this sketch; there are only three “A” axes in the Trigonal and Hexagonal crystal systems, not the four pictured.

Hexagonal, Trigonal, and Tetragonal Indicatrix



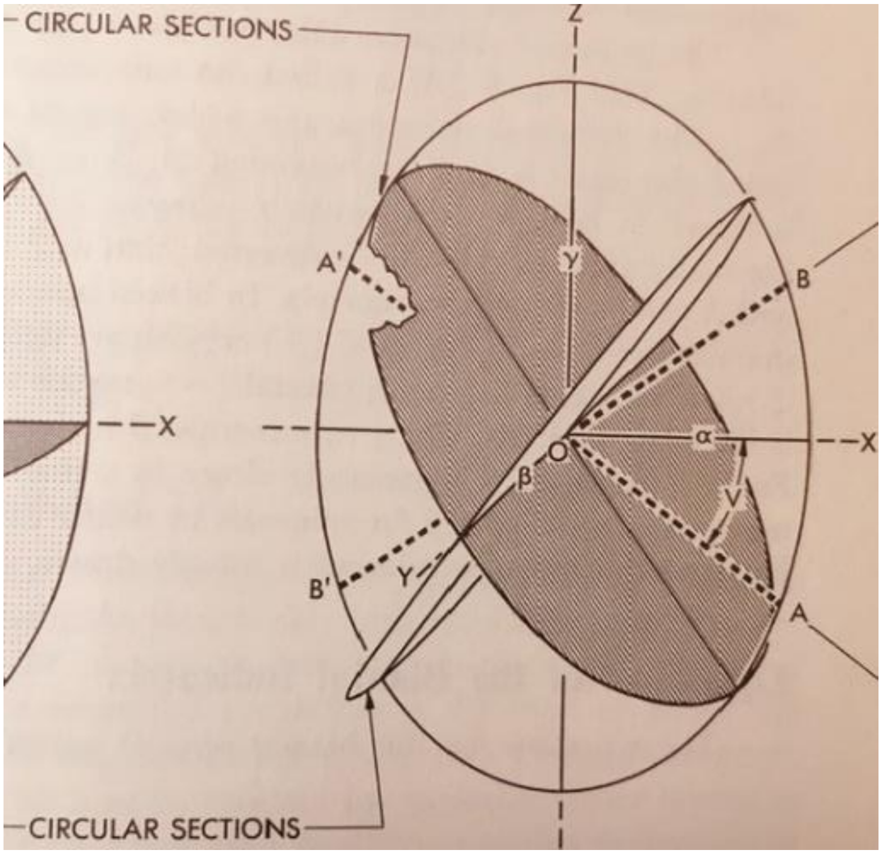
There is one **Circular Section** in a Uniaxial Indicatrix which has the diameter of the “A” Axes.

Orthorhombic, Monoclinic, and Triclinic Indicatrix



The dark surface is an **Oval Section**, *not a Circular Section as in a Uniaxel lndicatrix.*

Orthorhombic, Monoclinic, and Triclinic Indicatrices have two “Optic Axes” (doted lines “A” and “B” below), each with a Circular Sections. One pictured Circular Section is dark, the other clear.



Other considerations for faceters. With any crystal system mineral other than Cubic, where a non - Optic Axis orientation is chosen, light is split into two paths like the Calcite example above. For example, if a Zircon (Tetragonal) is cut with the Table Facet at a right angle to the “C” Axis or “Optic Axis” the gem looks normal. Any other orientation causes two views: the lines between facets on the Pavilion, or back side, appear to be doubled. The facets look fuzzy with a loss of definition. This is an easy optical test to confirm a gem is Zircon as most small crystals are cut as ovals, with the Table Facet parallel to the “C” Axis for maximum yield. Larger gems may be ‘correctly cut’ with the Table Facet at a right angle to the “Optic Axis” to eliminate the fuzzy appearance. Fuzzy facets can be a problem depending on the difference between the two Refractive Indices of Tetrahedral, Hexagonal and Trigonal minerals, or the difference between the intermediate and one or the other of the two extreme Refractive Indices of Orthorhombic, Monoclinic, and Triclinic minerals. A faceter’s choice of orientation (or lack of knowledge) may be significant in fuzzy facets.

The other factor is the thickness of the gem. For example, fuzzy facets become a problem in Quartz only when the gem is large because the difference in Quartz’ two Refractive Indexes are so small: it takes a thick piece of Quartz to cause the facet lines to appear doubled. Quartz’ Refractive Indices are 1.544 and 1.553, the difference or *Birefringence* is .002. Facet quality Zircon’s Refractive Indices are 1.924 and 1.980 with a Birefringence of .056. Birefringence is another way of identifying the fuzzy facet potential; the higher the Birefringence number the more likely fuzzy facets *may be* a problem, especially for larger gems. Cubic minerals have no Birefringence because they have but one Refractive Index, and therefore, no fuzzy facets.