Uniaxial minerals (Tetragonal and hexagonal systems)

Calcite:

Example of ray paths and vibration directions

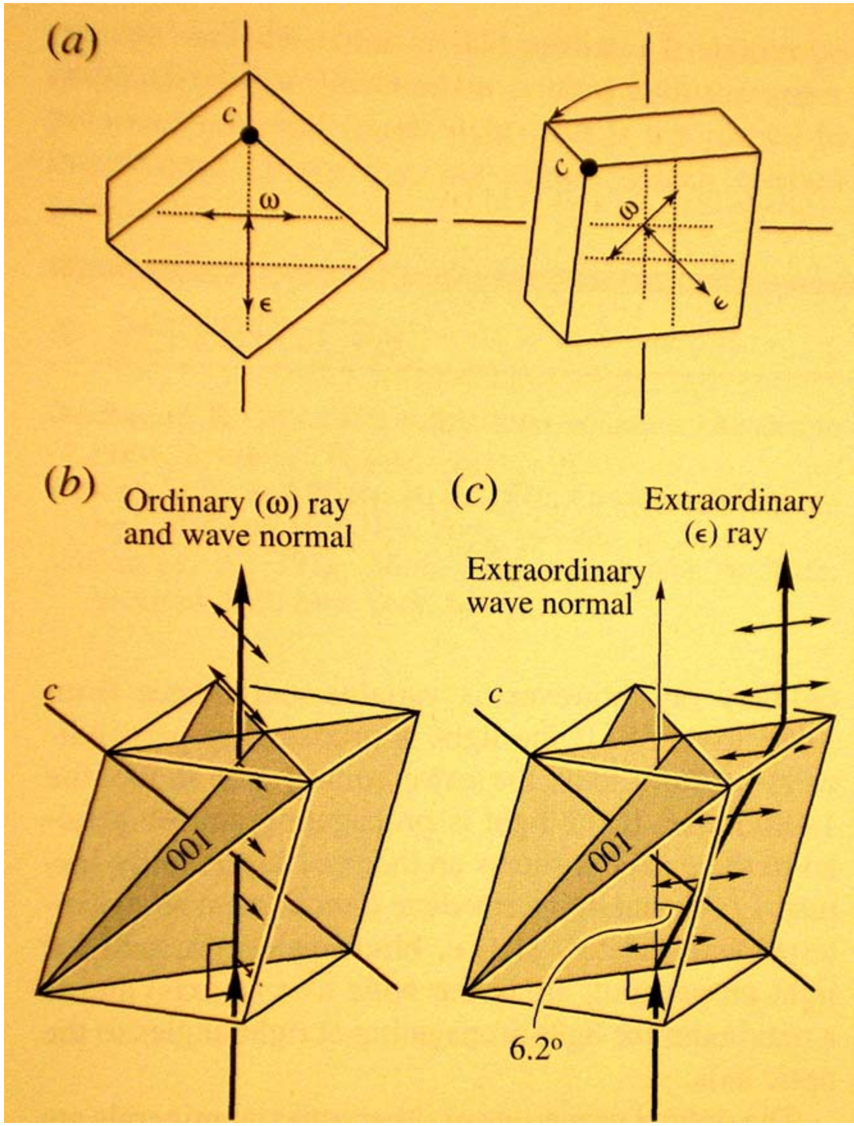
Extraordinary ray **(ε)** vibrates in a plane containing c-axis and ray path

Ordinary ray **(ω)** vibrates in plane perpendicular to ε ray. The vibration vector of **ω** always lies in the (0001) plane, i.e, perpendicular to the c-axis.

For light traveling along the c-axis, uniaxial minerals behave isotropically. This direction is called the optic axis.

In calcite, $n_{\omega} = 1.658$ and is constant regardless of direction of light propagation in the calcite. However, n_{ε} will vary from 1.486 to 1.658 depending on the direction. For light propagating perpendicular to c, $n_{\varepsilon} = 1.486$ and n_{ε} has intermediate values in all other directions

Birefringence is zero for light propagating along the optic axis and maximum for light propagating at right angles to the optic axis.



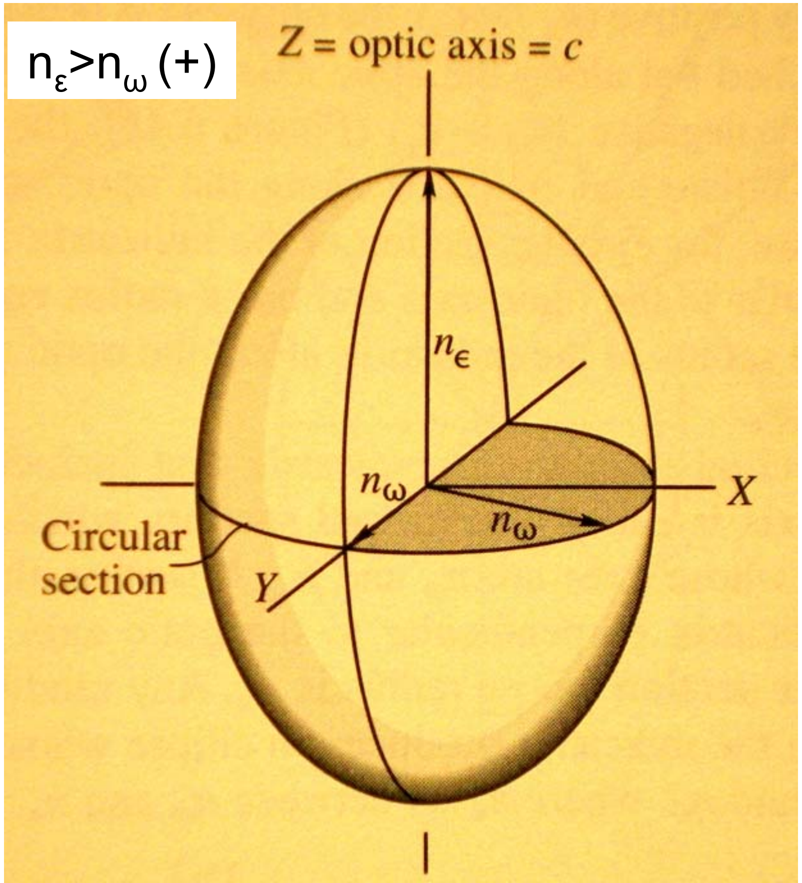
From: Nesse (2004) Optical Mineralogy. Oxford

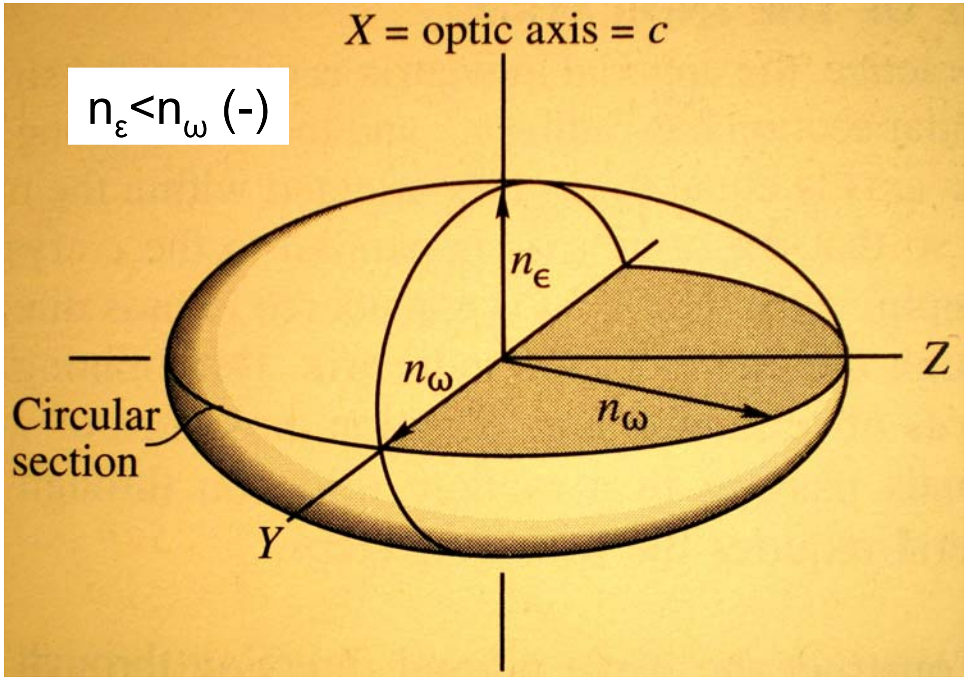
Uniaxial minerals (cont.)

Uniaxial indicatrix:

Biaxial ellipsoid with axes n_ε and n_ω. n values are plotted as radii parallel to the vibration directions. Circular section, principal section

Optic axis—c axis
Optic sign (+ or -)





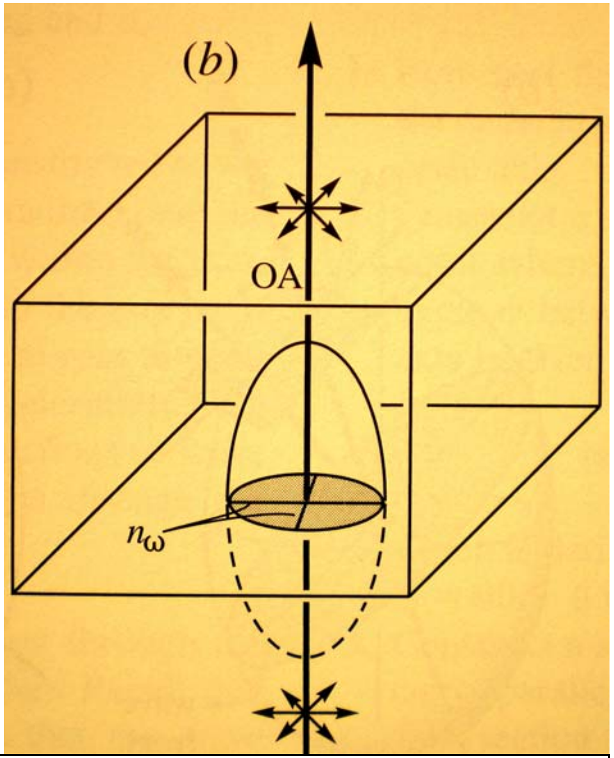
The indicatrix can be used for a variety of purposes which we will not elaborate on at present.

From: Nesse (2004) Optical Mineralogy. Oxford

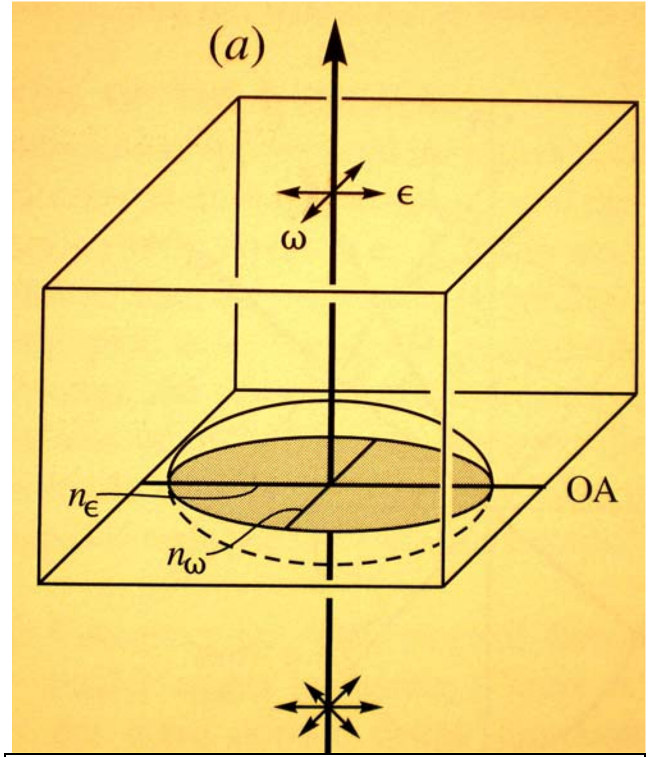
Uniaxial minerals (cont.)

Birefringence and interference colors

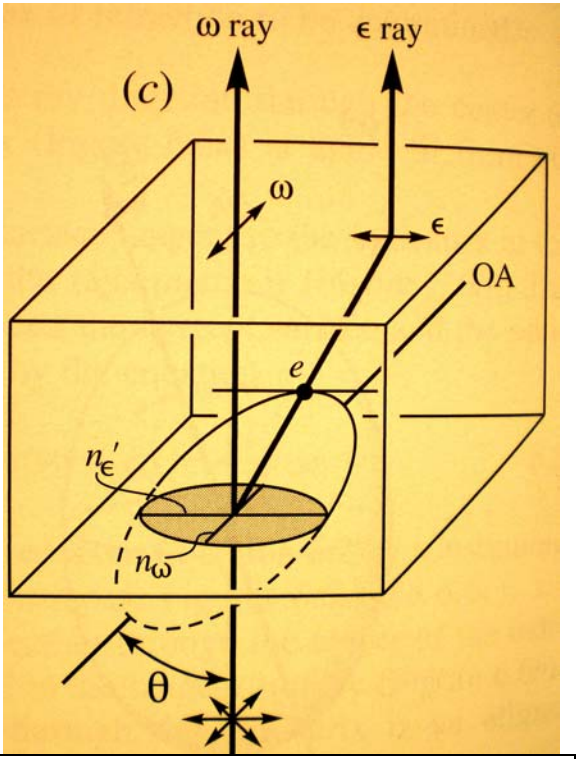
In the examples below, light is incident normal to the lower surface of mineral, i.e., wavefronts are not refracted and remain parallel to the lower surface



In this case, light passes along OA as ω ray and retains its vibration direction. Birefringence is zero and mineral remains dark as stage is rotated



In this case light is split into ω and ε rays. Birefringence is a maximum (highest interference color when in the 45º position)

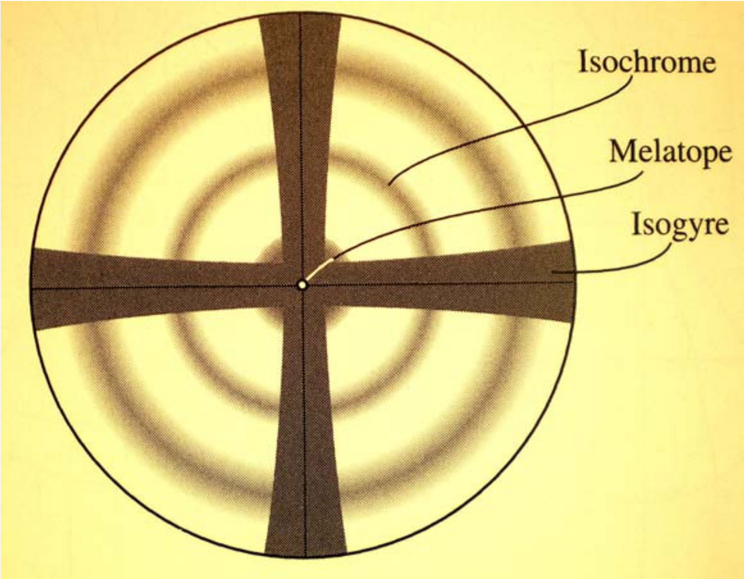


Random cut. Light is split in ω and ε' rays giving intermediate birefringence and less than maximum interference colors

From: Nesse (2004) Optical Mineralogy. Oxford

Uniaxial interference figures

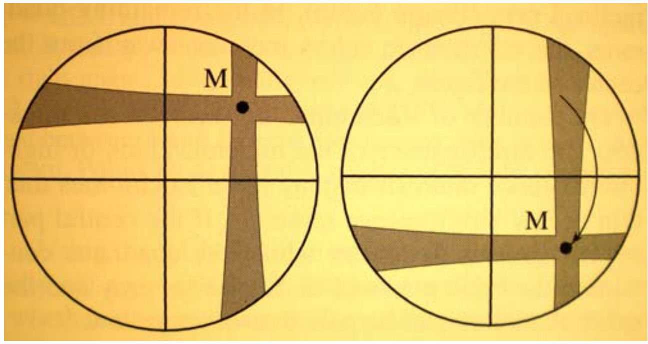
Used to determine if mineral is uniaxial or biaxial and for determining optic sign



To obtain an interference figure:

1. Focus on a sample with high power objective
2. Flip in the auxiliary condenser lens to provide conoscopic illumination: light now impinges on the sample at an angle that increases outwards
3. Cross the polarizers
4. Insert the Bertrand lens

Do all that and you may or may not observe an interference figure. If you are fortunate enough to have a uniaxial mineral that is oriented with its optic axis (c-axis) perpendicular to the stage, you will see a figure resembling the one shown. This is called a centered figure and the cross will remain stationary as the stage rotates. The higher the birefringence of a mineral, the sharper the interference figure will be.



If the optic axis is inclined you might see an off-center interference figure, which can still be used to determine the optic sign. If the OA is seriously inclined you will not see this figure.

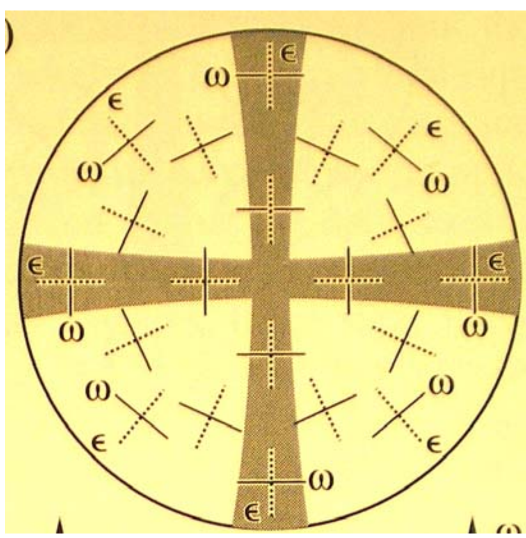
From: Nesse (2004) Optical Mineralogy. Oxford

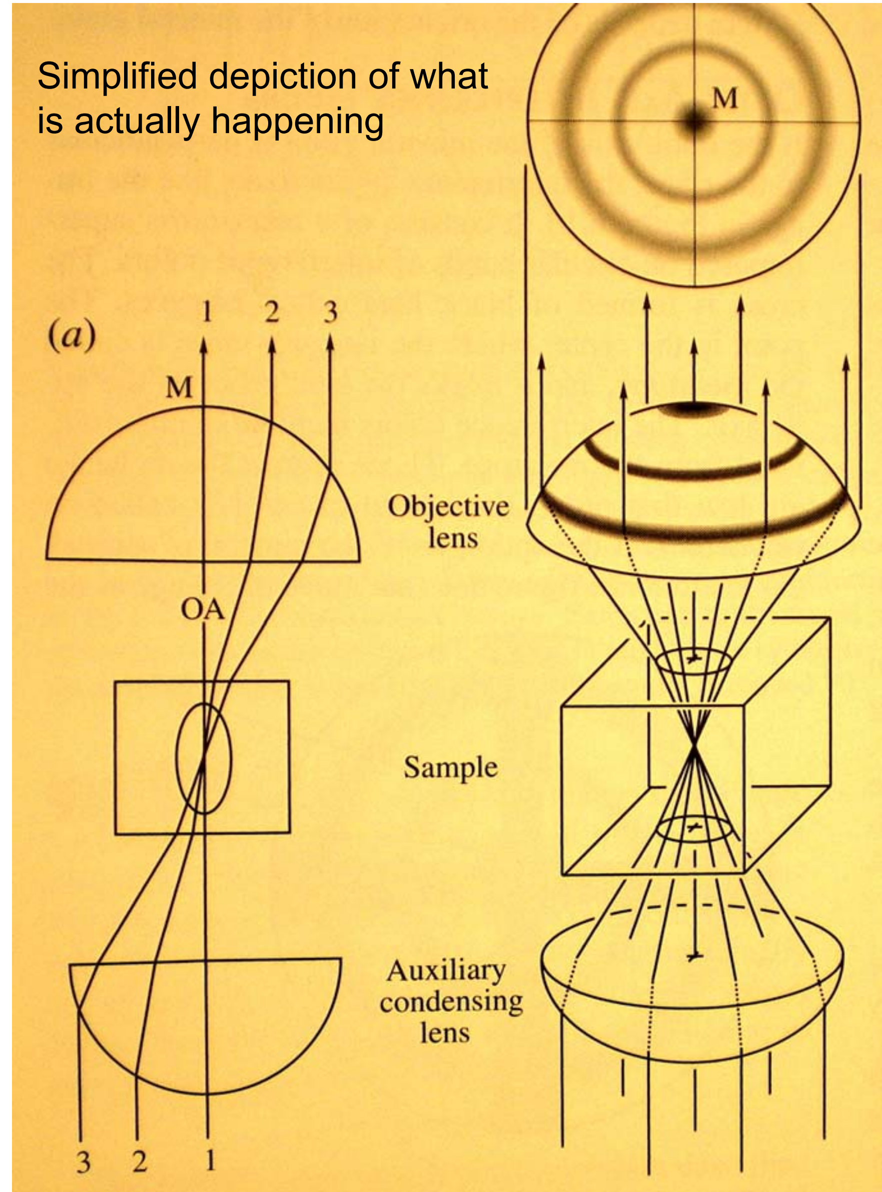
How is the uniaxial interference figure produced?

Isochromes form concentric circles in a centered uniaxial figure. For path 1, light is not split into two rays (Δ and δ are zero). For path 2, the cone of light has moderate retardation because n_{ε}' is close to n_{ω}. For path 3, $n_{\varepsilon}' - n_{\omega}$ is larger **and** the path through the crystal is longer so retardation (Δ) and birefringence (δ) are higher.

Isogyres form when the vibration directions of the ω and ε rays are parallel to the vibration directions of the polarizer (E-W) and analyzer (N-S), i.e., they are areas of extinction.

ω rays vibrate tangentially and ε rays vibrate radially





From: Nesse (2004) Optical Mineralogy. Oxford

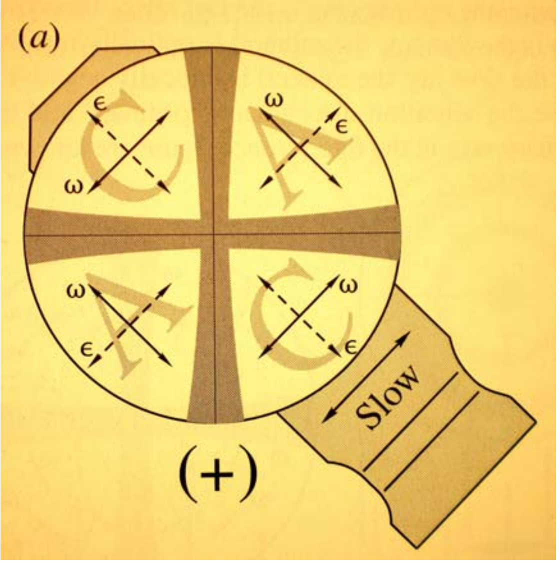
Determination of optic sign in uniaxial minerals

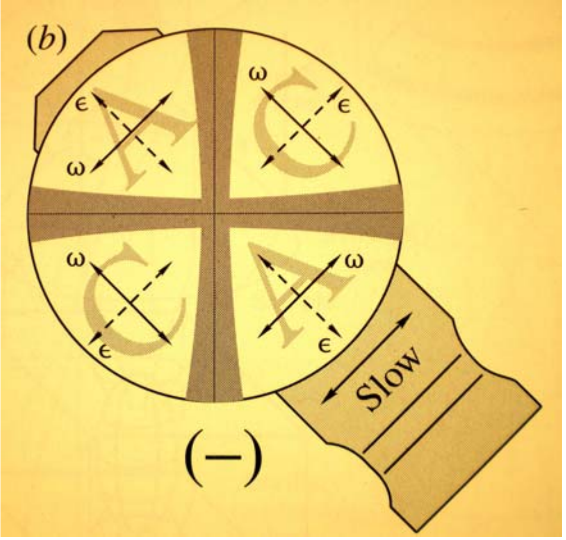
1. Locate a centered or near-centered uniaxial interference figure. You will get best results by locating a grain showing the **lowest** birefringence, i.e., one in which the optic axis is near-vertical.

2. If the figure is off-center, make sure you know which quadrant you are dealing with.

3. Insert the gypsum compensating plate (530 nm) and observe the color change in the immediate vicinity of the melatope. For a positive mineral, ω is faster than ε, so we have slow on fast and some cancellation of retardation in the NW and SE quadrants . These quadrants will be yellow adjacent to the isogyres while the NE and SW quadrants will be blue.

4. For a negative mineral, you will observe the opposite effect.





From: Nesse (2004) Optical Mineralogy. Oxford

Common Uniaxial Minerals

Positive: Quartz, Ice, Brucite, Stishovite, Zircon, Rutile, Cinnabar

Negative: Melilite, Nepheline, Beryl, Apatite, Calcite, Dolomite, Magnesite, Ankerite, Corundum, Ilmenite, Hematite, Tourmaline

1. Examine one of the **quartzite** thin sections in the microscope. This is a metamorphosed quartz arenite containing >90% quartz with the rest being microcline, plagioclase, muscovite and chert.

a. Look for a quartz grain with the highest birefringence, i.e., one in which the principal section (c-axis) is parallel to the stage. This would be first order white with a tinge of yellow. Assuming that this is a properly made thin section it should be 30 microns thick. Determine the **birefringence** of quartz by using the interference color chart.

b. Does quartz show **pleochroism**? Does quartz show **cleavage**?

c. Locate a quartz--microcline contact (I'll help) and using the Becke line test determine which mineral has the highest **refractive index.**

d. What optical effect would you use to locate a grain that is cut ⊥ c-axis? Locate such a grain (or as close as you can get). You are now looking down the optic axis, i.e., the **c** axis, with the circular section of the indicatrix parallel to the stage. Focus the grain with the high powered objective under crossed polars—make sure the lens is centered. Flip in the condensing lens and the Bertrand lens. Adjust condensing lens so that the small circle of light is maximized in size. If you did it correctly, you will see an **optic axis interference figure**. **Make a sketch of what you see and compare with Figs. 7.35 in Nesse.**

e. Use the accessory plate (gypsum plate) to determine the **optical sign** of the quartz (positive or negative). [The interference figure does not have to be perfectly centered to determine the sign as long as you can recognize which quadrant you are in.] Sketch the optic axis interference figure indicating the colors in the four quadrants: Find another grain with high birefringence. Using the same set-up as above, find a "flash figure".

f. Determine the range of grain sizes and the average grain size from your calibration of the crosshairs. At 40x, one division = 24 μm, at 100x, one div. = 9.6 μm, at 400x, I div = 2.4 μm

g. Do you have any explanation of why the extinction in quartz is not sharp? This phenomenon is commonly referred to as "**undulatory extinction**."

2. Examine one of the marble thin sections **(E23F or V20 or AB89-6.6).** The most abundant mineral in these thin sections is calcite—it forms the interstitial matrix. [Other minerals include olivine, phlogopite and diopside—ignore these]. Carbonates are usually quite easy to identify in thin section because of their extreme birefringence, rhombohedral (10$\bar{1}$1) cleavage and lamellar twinning: twin plane is (01$\bar{1}$2). However, it is difficult to distinguish calcite from dolomite from magnesite (staining techniques are commonly used).

a. Estimate the **birefringence** of calcite? Because calcite has very high birefringence (fifth or sixth order) this is difficult. You might want to try using the quartz wedge to do this.

b. Find an optic axis figure (you may need help on finding a section cut ⊥ c-axis). **Sketch** what you see including the **isochromes**. Determine optic sign; you may have to use a quartz wedge to do this since the birefringence of calcite is so high.

3. Magnet Cove, Arkansas

Thin sections of this rock contain three uniaxial minerals and two isotropic minerals. [The rock also contain green clinopyroxene and brown biotite which you should ignore for now]. Two of the uniaxial minerals (**apatite** and **calcite**) are accessory minerals (present in minor amounts) while the third one (**nepheline**) makes up ~60% of the rock. Try to locate the three uniaxial minerals and determine the optic sign for the nepheline. The brown isotropic mineral is a rare form of **garnet called melanite** that occurs in some alkalic igneous rocks. The other isotropic mineral is **pyrite** but, because it is opaque, it cannot be easily indentified in transmitted light. It is easily identified in reflected light, however.

4. In the sections containing quartz and epidote, locate a grain of **quartz** that gives a centered optic axis figure and determine the optic sign. Be careful to not to mistake holes in the section for c-axis section of quartz. Holes are filled with epoxy and can be identified easily.

[The other mineral in this section is **epidote**—it's biaxial so not the subject of this lab. However, note the third order (maximum) interference colors in epidote. Note also the anomalous interference colors in many grains—this is very typical of minerals in the epidote group. Note also the pleochroism of epidote.]