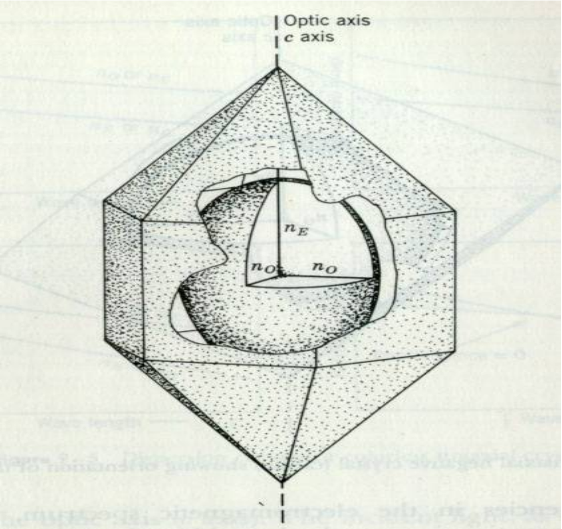
A simplified introduction to

Optical Mineralogy

For First Year Geology Students



Staff Members of Geology Dept

&

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Optical mineralogy

Optical mineralogy is the study of the optical properties of minerals using the polarizing microscope. In this simplified introduction, we will deal with the polarizing microscope and the optical properties of minerals and how can we study them using this type of microscopes.

The polarizing (transmitted-light) microscope is a determinative tool to differentiate between not only between the different mineral groups, but also between the different minerals of the same group depending on their optical properties, and thus on their crystal systems.

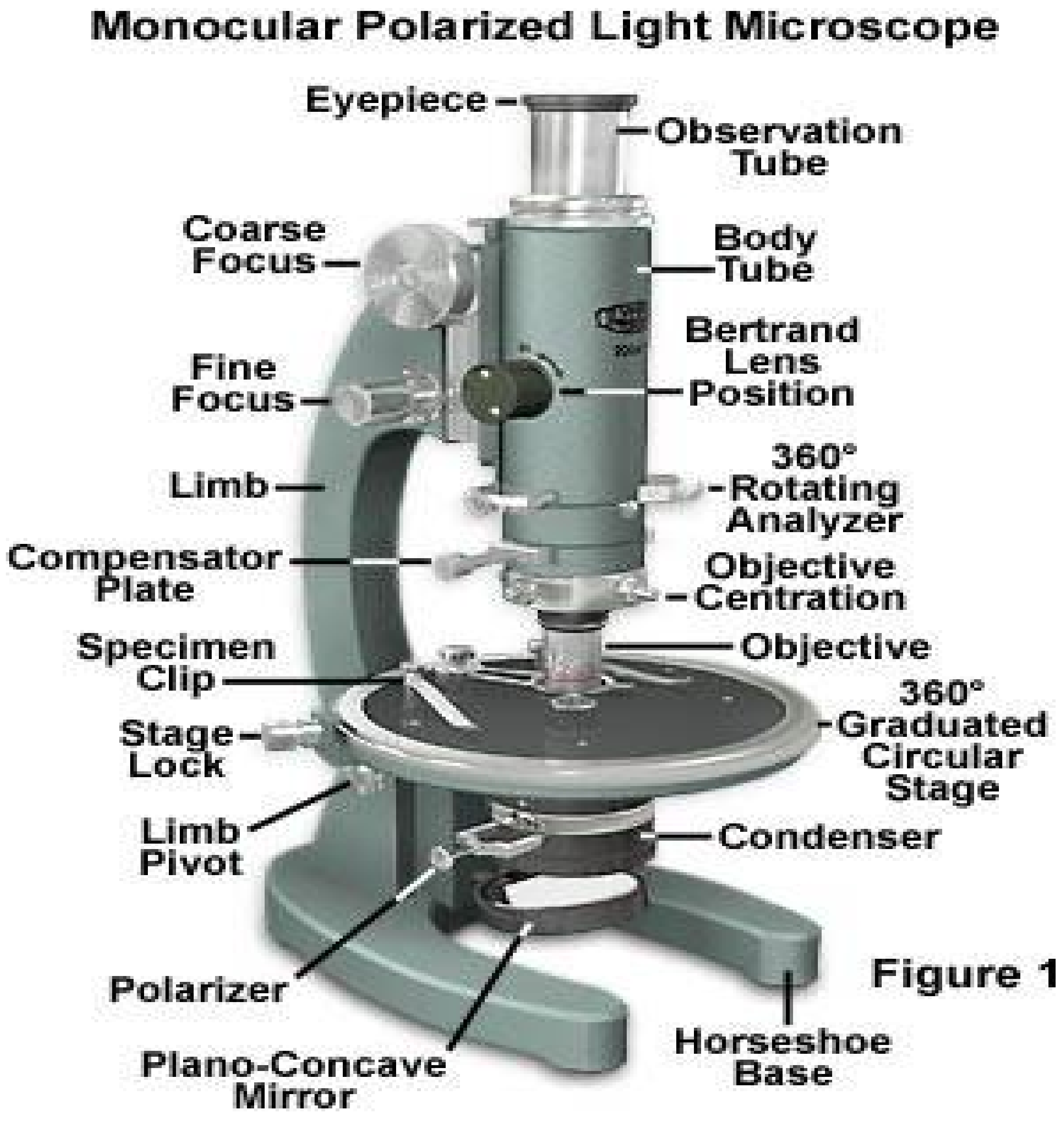
The polarizing microscope has two polaroids (also calledpolars ornicols) to polarize the normal white light (or even the monochromatic light) into light waves vibrating in one plane and adsorb waves of other directions. One polaroid is found over the light source and below the microscope stage and called the polarizer. The other polaroid is found between the objective and the ocular and called the analyzer. Eachpolaroid can be removed from the light path. The stage is rotatory and being divided into 360°.

The light source In transmitted-light studies a lamp is commonly built into the micro-scope base. The typical bulb used has a tungsten filament (A source) which gives the field of view a yellowish tint. A blue filter can be inserted immediately above the light source to change the light colour to that of daylight (C source).

In older microscopes the light source is quite separate from the microscope and is usually contained in a hooded metal box to which can be added a blue glass screen for daylight coloured light. A small movable circular mirror, one side of which is flat and the other concave, is attached to the base of the microscope barrel. The mirror is used to direct the light through the rock thin section on the microscope stage, and the flat side of the mirror should be used when a condenser is present.

The polarizer:

The assumption is that light consists of electromagnetic vibrations. These vibrations move outwards in every direction from a point source of 'white' light, such as a microscope light. A polarising film (the polariser) is held within a lens system located below the stage of the microscope, and this is usually inserted into the optical path. On passing through the polariser the light is 'polarised' and now vibrates in a single plane. This is called plane polarised light (PPL). In most UK microscopes the polariser is oriented to give E-W vibrating incident light .



Monocular Polarized Light Microscope

Figure 1

Substage diaphragms:

One or two diaphragms may be located below the stage. The field diaphragm, often omitted on simple student microscopes, is used to reduce the area of light entering the thin section, and should be in focus at the same position as the thin section; it should be opened until it just disappears from view. The aperture diaphragm is closed to increase resolution; it can be seen when the Bertrand lens is inserted.

The condenser

The condenser or convergent lens A small circular lens (the condenser) is attached to a swivel bar, so that itcan be inserted into the optical train when required. It serves to direct a cone of light on to the thin section and give optimum resolution for the objectives used. The entire lens system below the microscope stage, including polariser, aperture diaphragm and condenser, can often be racked upwards or downwards in order to optimise the quality of illumination. Some microscopes, however, do not possess a separate convergent lens and, when a convergent lens is needed, the substage lens system is racked upwards until it is just below the surface of the microscope stage.

The Rotating Satage

The microscope stage is flat and can be rotated. It is marked in degrees, and a side vernier enables angles of rotation to be accurately measured. The stage can usually be locked in place at any position. The rock thin section is attached to the centre of the stage by metal spring clips.

Objectives:

Objectives are magnifying lenses with the power of magnification inscribed on each lens (e.g. x5, x30). An objective of very high power (e.g. xl 00) usually requires an immersion oil between the objective lens and the thin section.

Eyepiece:

The eyepiece (or ocular) contains crosswires which can be independently focused by rotating its uppermost lens. Eyepieces of different magnification are available. Monocular heads are standard on student microscopes. Binocular heads may be used and, if correctly adjusted, reduce eye fatigue.

The analyser:

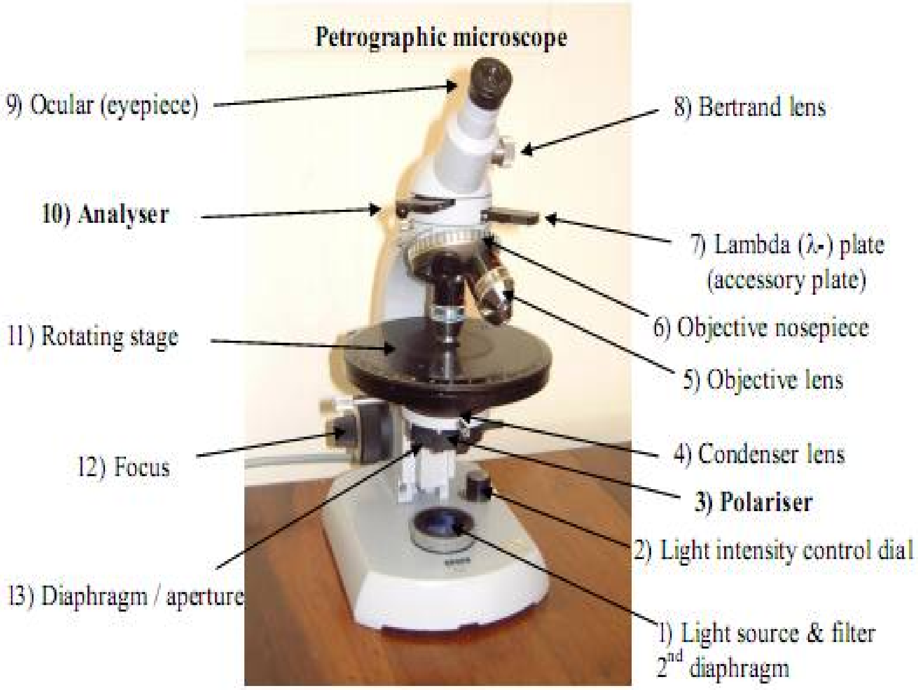
The analyser is similar to the polariser; it is also made of polarising film but oriented in a N-S direction, i.e. at right angles to the polariser. When the analyser is inserted into the optical train, it receives light vibrating in an E-W direction from the polariser and cannot transmit this; thus the field of view is dark and the microscope is said to have crossed polars (CP, XPOLS or XP). With the analyser out, the polariser only is in position; plane polarised light is being used and the field of view appears bright.

The Bertrand lens:

This lens is used to examine interference figures (see Section 1.3.2). When it is inserted into the upper microscope tube an interference figure can be produced which fills the field of view, provided that the convergent lens is also inserted into the optical path train.

The accessory slot:

Below the analyser is a slot into which accessory plates, e.g. quartz wedge, or first order red, can be inserted. The slot is oriented so that accessory plates are inserted at 45° to the crosswires. In some microscopes the slot may be rotatable.



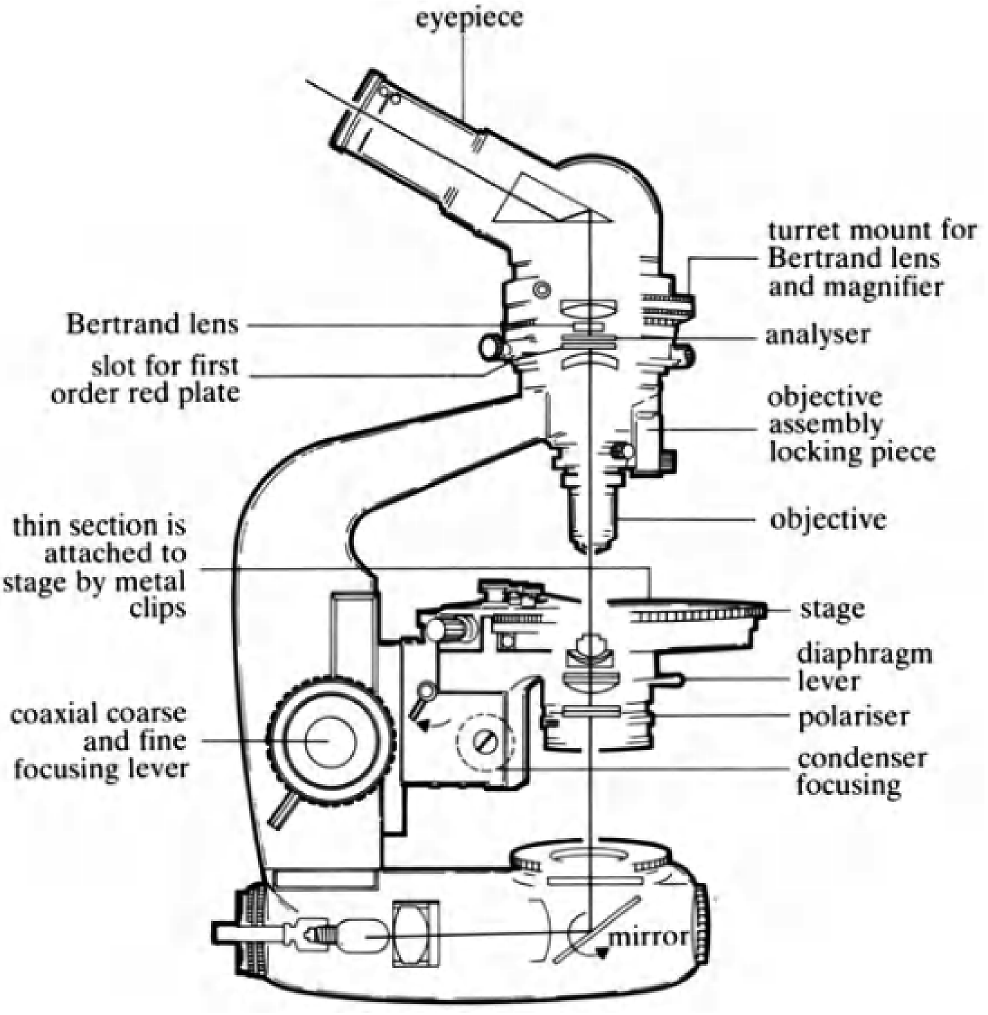
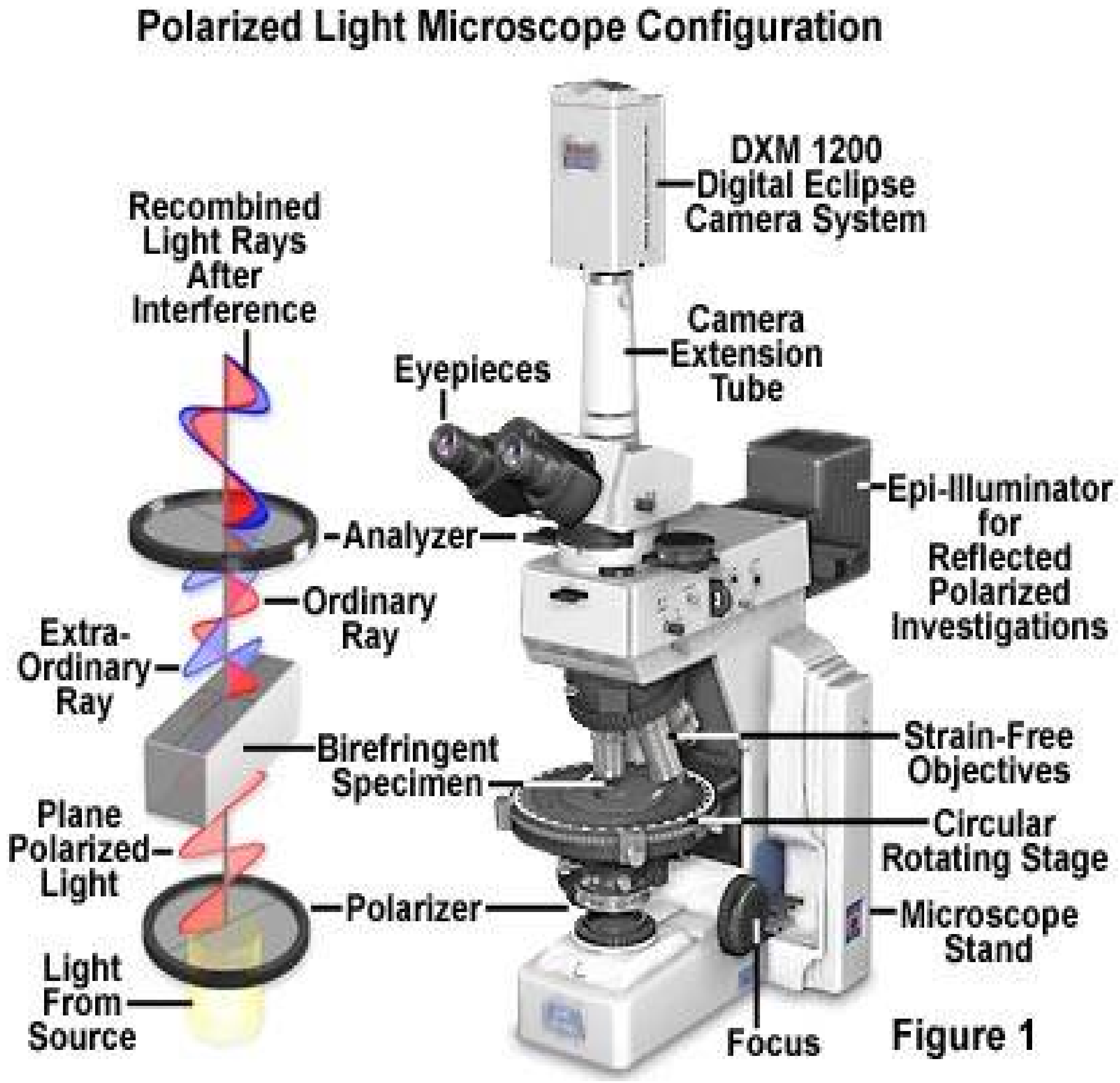


Figure 1.2 Modern transmitted light microscope. Older models may focus by moving the upper barrel of the microscope (not the stage as in the illustration), and may use an external light source. The illustration is based on a Nikon model POH-2 polarising microscope.

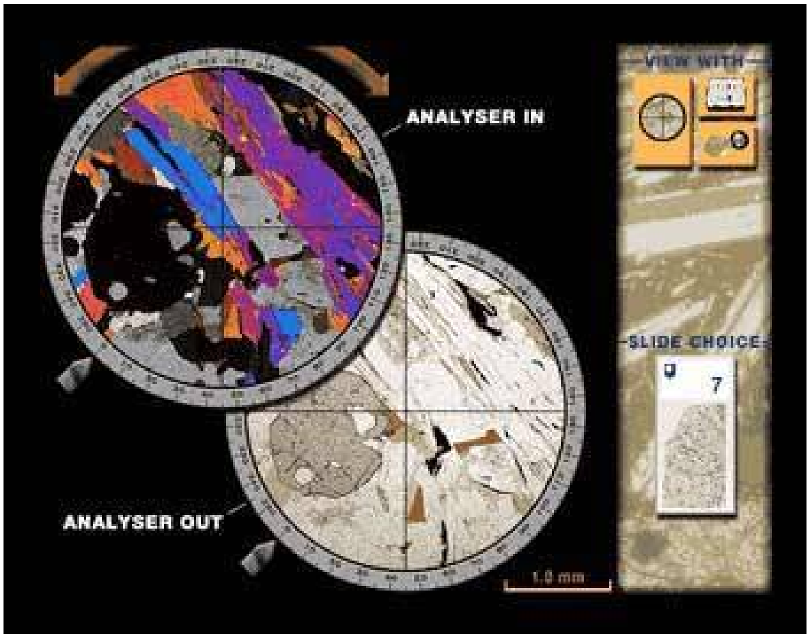

Polarized Light Microscope Configuration
DXM 1200 Digital Eclipse Camera System
Recombined Light Rays After Interference
Camera Extension Tube
Eyepieces
Epi-Illuminator for Reflected Polarized Investigations
Analyzer
Ordinary Ray
Extra-Ordinary Ray
Birefringent Specimen
Strain-Free Objectives
Plane Polarized Light
Circular Rotating Stage
Polarizer
Microscope Stand
Light From Source
Focus
Figure 1

Adjustment of the polarizing microscope

Each time we work with the polarizing microscope, we have to make sure of three things: **1**- the microscope is centered, **2**- the vibration plane of the polarizer is determined, and **3**- the vibration directions of the polaroids (nicols) are perpendicular to one another (crossed).

1- Centering the microscope:

Centering is that the axis of the microscope tube coincides with the axis of rotation and the optic axis of the ocular lens.When we put a mineral grain (as small as possible) in the intersection of the crosshairsand rotate the microscope stage, if the microscope is centered the grainwould rotate *in situ*. If the mineral grain makes a circle with a center away of the crosshairs, we use the centering screws of the objective to move the grain so as to make its center of rotation circle coincides with the crosshairs. This is by bulling it against the imaginary center with the same distance. Then we bring the grain (the same or another) back to the crosshairs by moving the slide by hand and rotate the stage to see whether centered or not yet, to repeat until full centering.



2- Determination the vibration direction of the polarizer:

To perform that, a thin section of a rock containing the mineral biotite is used. Biotite shows change in color upon rotation of the microscope stage (pleochroism) from yellow to dark brown. Biotite is darkest when its cleavage is parallel to the vibration direction of the polarizer, so we can determine the vibration direction of the polarizer.

In many microscopes the polarizer is fixed so that the polarized light vibrates in the E-W direction. So, in microscopes with rotatable polarizers, we put the biotite grain so that the cleavage is parallel to the horizontal hair (E-W hair), and rotate the polarizer to get the darkest color, then the polarizer is adjusted at the E-W direction.

3- Crossing the nicols:

When the two nicols are in the light path, the field of view must be in complete darkness (in absence of any mineral slides), and this indicates that both nicols are crossed. If not, we rotate the analyzer to get the complete darkness, then they are crossed and the vibration direction of the analyzed is N-S.

Nature of light:

Light is a form of radiant energy, and expresses the visible portion of the spectrum from 410 nm of the violet to 700 nm of the red.

Visible light is a small portion of a continuous spectrum of radiation ranging from cosmic rays to radio waves.

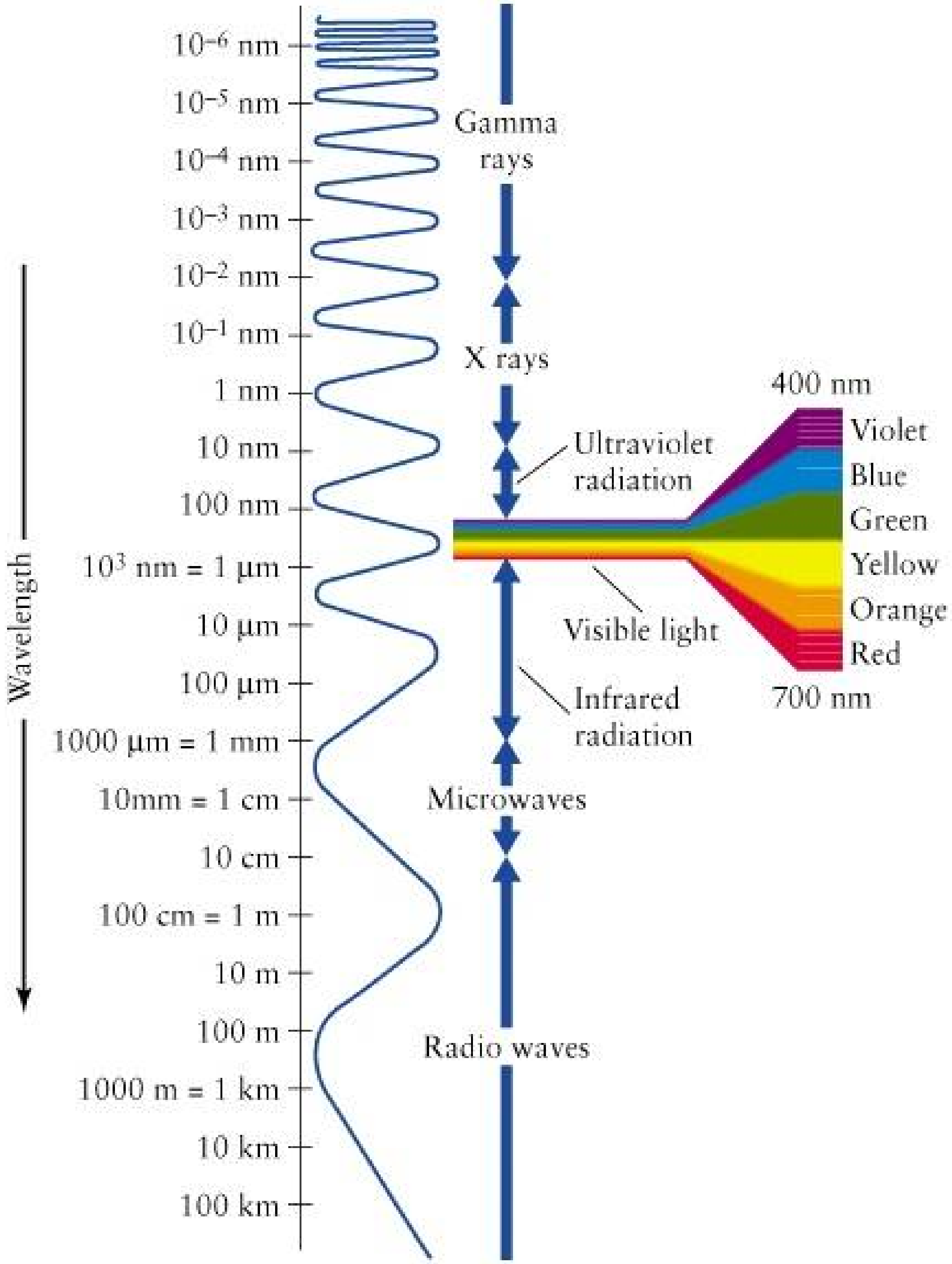
Two complimentary theories have been proposed to explain how light behaves and the form by which it travels.

1- Particle theory - release of a small amount of energy as a photon when an atom is excited.

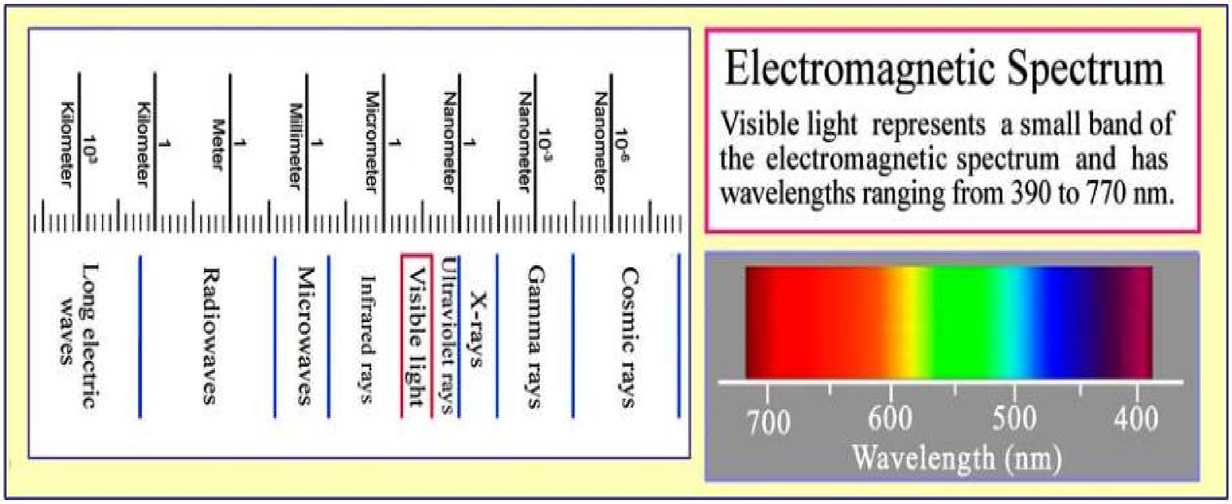
2- Wave theory - radiant energy travels as a wave from one point to another.

Waves have electrical and magnetic properties => electromagnetic variations.

Wave theory effectively describes the phenomena of polarization, reflection, refraction and interference, which form the basis for optical mineralogy.

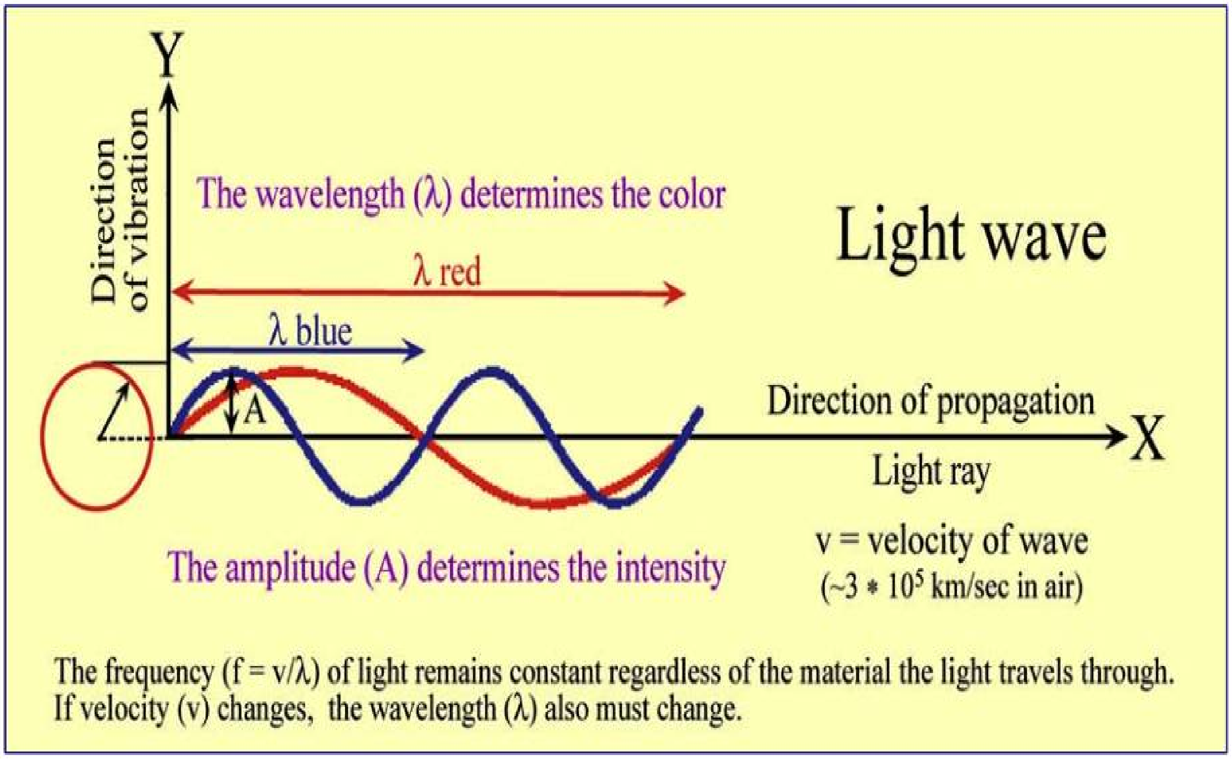


Electromagnetic spectrum



Electromagnetic Spectrum

Visible light represents a small band of the electromagnetic spectrum and has wavelengths ranging from 390 to 770 nm.



The wavelength (λ) determines the color

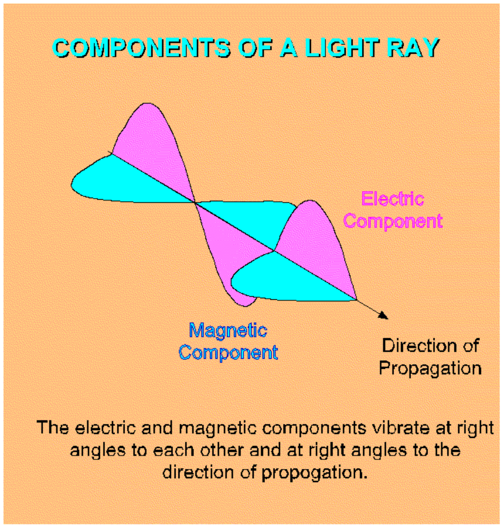
The amplitude (A) determines the intensity

v = velocity of wave
(~3 * 10^5 km/sec in air)

The frequency ($f = v/\lambda$) of light remains constant regardless of the material the light travels through. If velocity (v) changes, the wavelength (λ) also must change.

Components of a Light Ray

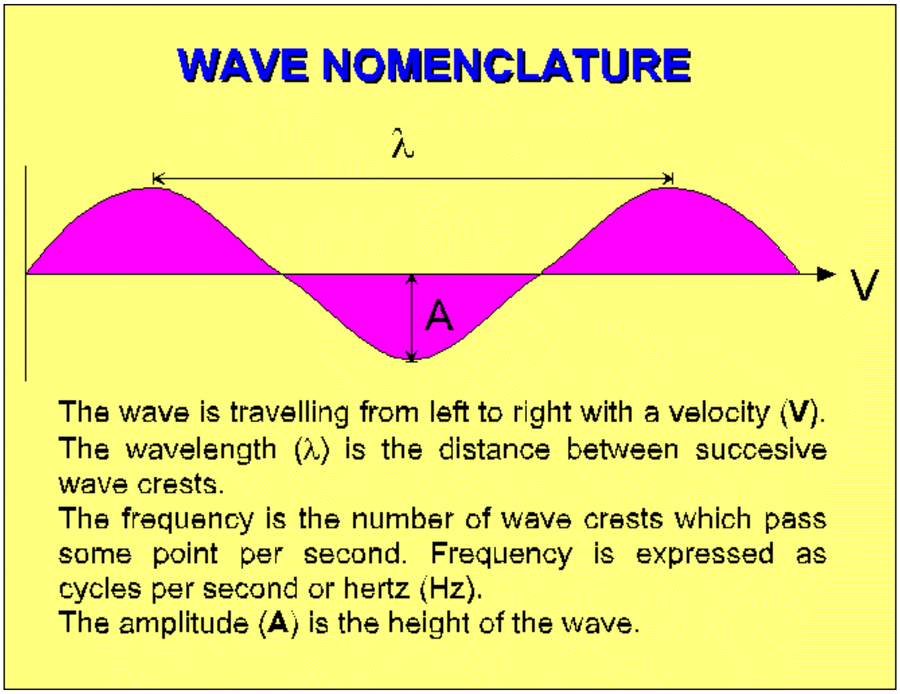
The electromagnetic radiation theory of light implies that light consists of electric and magnetic components which vibrate at right angles to the direction of propagation.



The electric component (electric vector) is considered and is referred to as the ***vibration direction*** of the light ray, and is perpendicular to the direction in which the light is propagating.

The behavior of light within minerals depends on the atoms and the chemical bonds within these minerals.

Light waves are described in terms of **velocity, frequency and wavelength**.



WAVE NOMENCLATURE

The wave is travelling from left to right with a velocity (**V**).
The wavelength (λ) is the distance between succesive wave crests.
The frequency is the number of wave crests which pass some point per second. Frequency is expressed as cycles per second or hertz (Hz).
The amplitude (**A**) is the height of the wave.

The velocity of light (V) and the wavelength (λ) are related in the following equation,

$$\mathbf{F=V/\lambda}$$

where: **F** = Frequency or number of wave crests per second which pass a reference points => cycles/second of Hertz (Hz).

F is constant, regardless of the material through which the light travels.

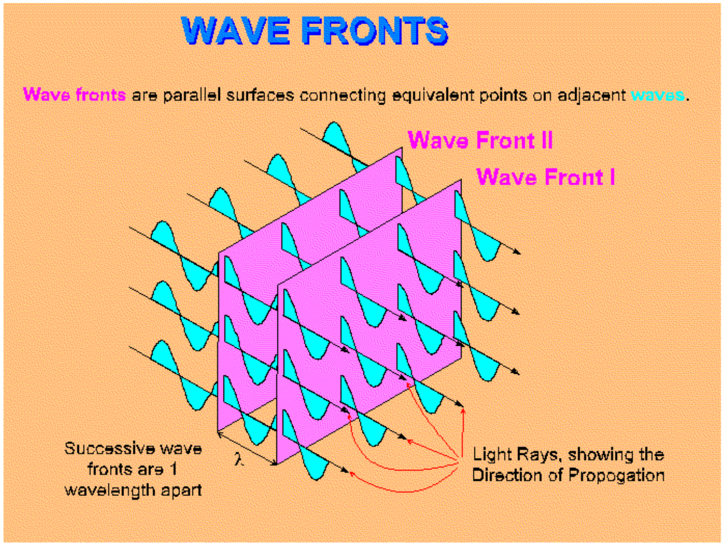
So when **V** changes (decreases), then λ must change (increases) to maintain constant F.

WAVE FRONT and WAVE NORMAL

Wave front Wave fronts are parallel surfaces, each connects similar or equivalent points on adjacent waves.

Wave Normal is a line perpendicular to the wave front, representing the direction of the wave motion.

Light Ray is the direction of propagation of the light energy.



Minerals can be subdivided, based on the interaction of the light ray travelling through the mineral and the nature of the chemical bonds holding the mineral together, into two classes:

Isotropic Minerals, in which light shows the same velocity in all directions because the chemical bonds holding the minerals together are the same in all directions, so light travels at the same velocity in all directions.

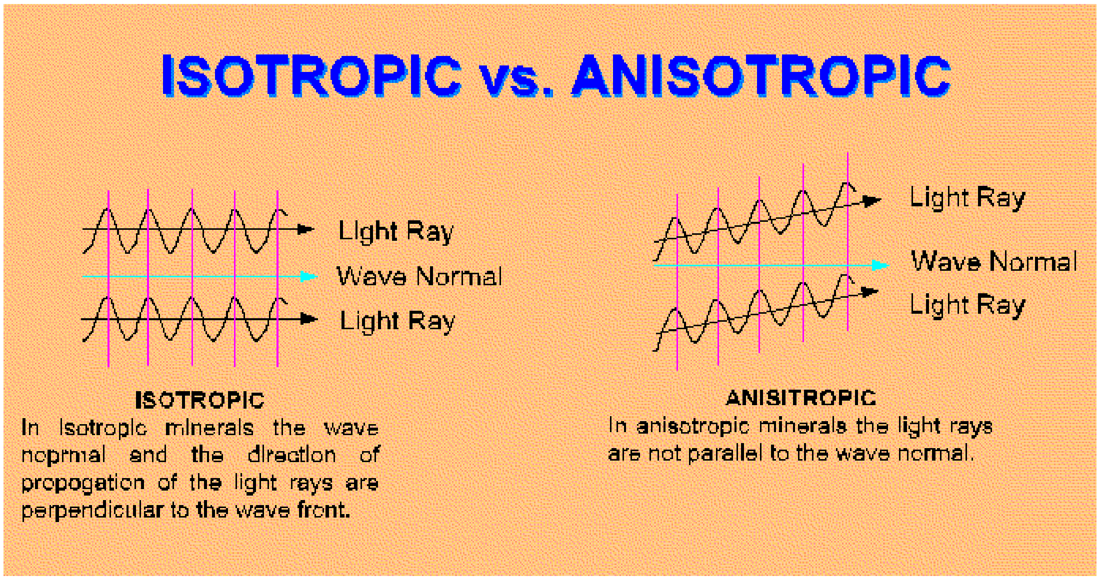
Examples of isotropic material are volcanic glass and isometric minerals (cubic) Fluorite, Garnet, Halite

In isotropic materials the Wave Normal and Light Ray are parallel.

In anisotropic minerals, light has a different velocity, depending on the direction in which it travels through the mineral. The chemical bonds holding the mineral together will differ depending on the direction the light ray travels through the mineral.

Anisotropic minerals belong to tetragonal, hexagonal, orthorhombic, monoclinic and triclinic systems.

In anisotropic minerals the Wave Normal and Light Ray are not parallel.



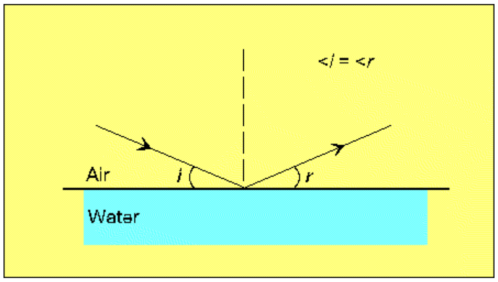
In Isotropic minerals the wave noprmal and the direction of propogation of the light rays are perpendicular to the wave front.

In anisotropic minerals the light rays are not parallel to the wave normal.

Light waves travelling along the same path in the same plane will interfere with each other.

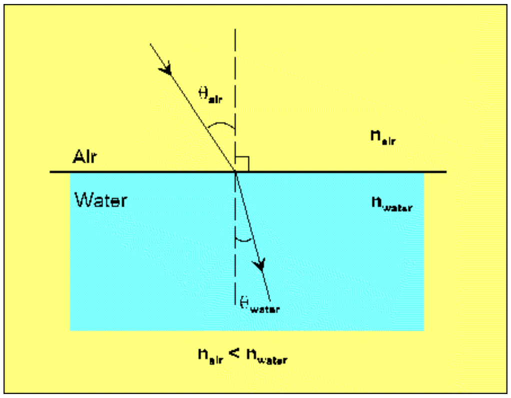
Ordinary light: Vibrating in all directions normal to the propagation direction.

REFLECTION AND REFRACTION OF LIGHT



For Reflection the angle of incidence = angle of reflection.

In Refraction the light is bent when passing from one material to another, at an angle other than perpendicular.



The Index of Refraction (Refractive index) **n** is a measure of how effective a material is in bending light.

The refractive index, (**RI**)or **n**, of a material is defined as **the ratio of the speed of light in a vacuum, V_{vac}, to the speed of light in a material through which it passes, V_m.**

$$\boxed{n = V_{vac} / V_m}$$

In general, V depends on the density of the material, with V_m decreasing with increasing density. Thus, higher density materials will have higher n.

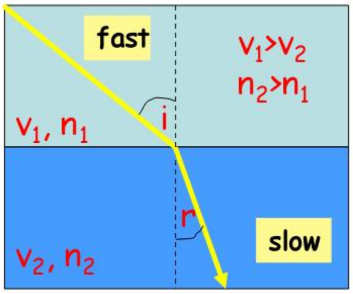
Note **n** will always be > 1.0, since V_m can never be greater than V_{vac}.

Most minerals have **n** values in the range 1.4 to 2.0.

A high Refractive Index indicates a low velocity for light travelling through that particular medium.

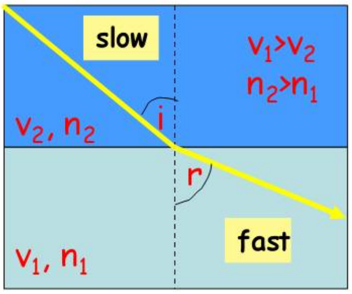
Snell's Law : Snell's law can be used to calculate how much the light will bend on travelling into the new medium. Light is refracted towards the normal on entering the material with a higher refractive index and is refracted away from the normal on entering the material with lower refractive index.

Case 1 (from fast to slow)



Light beam bends toward the normal (smaller r)

Case 2 (from slow to fast)



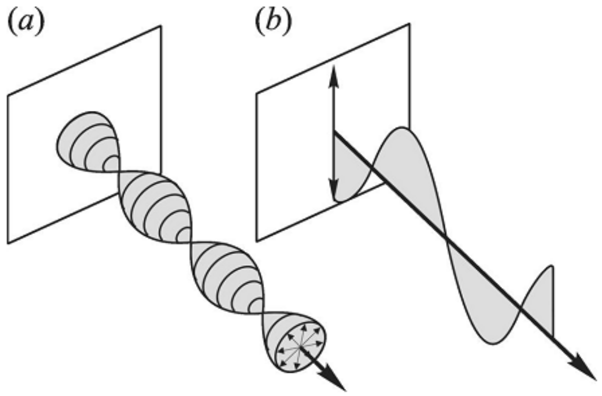
Light beam bends away from the normal (larger r)

$$V_{vac} / V_m = \sin i / \sin r = n_m / n_{vac}$$

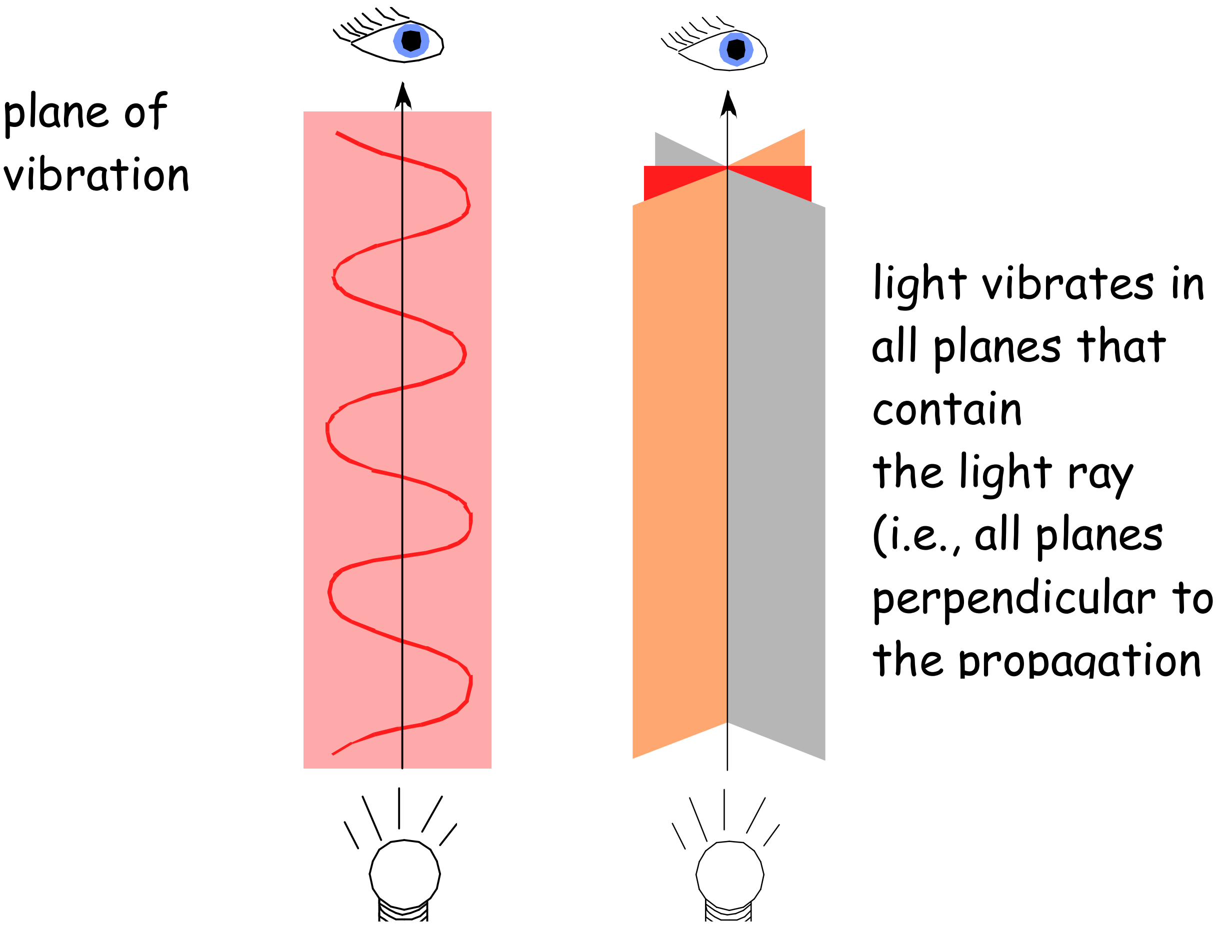
$$n_{vac} \sin i = n_m \sin r , \; n_{vac} = 1$$

$$\boxed{n_m = \sin i / \sin r}$$

Polarized light: Vibrating in one direction (one plane) normal to the propagation direction.



Polarized light. (*a*) Unpolarized light vibrates in all directions at right angles to the direction of propagation. (*b*) Plane-polarized light. The electric vector vibrates in a single plane.

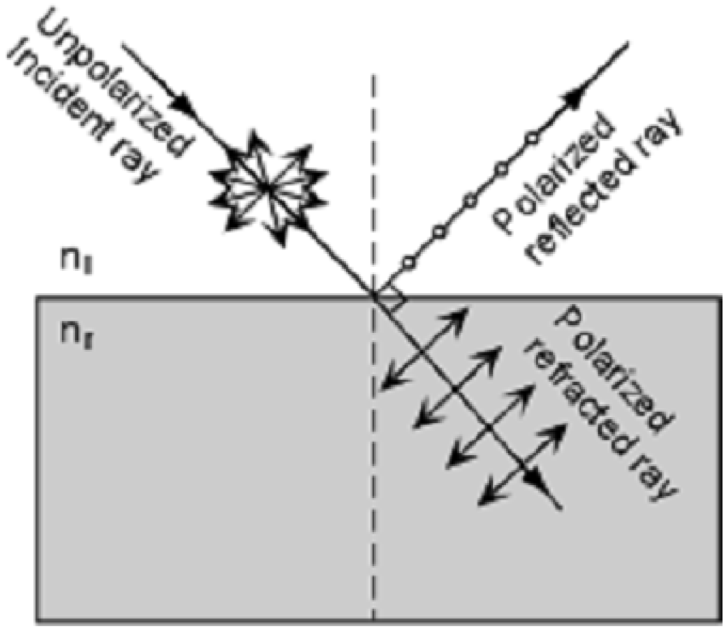


How to get polarized light??

There are two common ways that light can become polarized.

1 - Reflection off of a non-metallic surface, such as glass or paint. When a beam of ordinary light strikes such a surface and is reflected, it will be polarized with vibration directions parallel to the reflecting surface.

If some of the ordinary light also enters the material and is refracted at an angle 90 to the path of the reflected ray, it too will become partially polarized, with vibration directions perpendicular to the path of the refracted ray, but in the plane perpendicular to the direction of vibration in the reflected ray



2 - **Using substances that absorb light vibrating in all directions except one.**

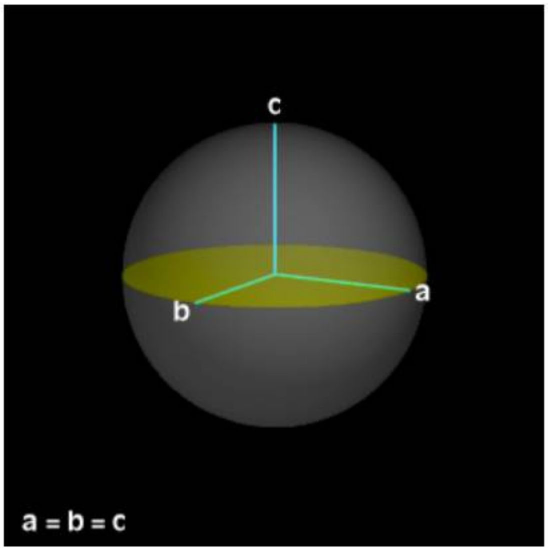
These substances are represented mainly by anisotropic crystals and artificial polaroids. **Anisotropic crystals** have the property of absorption of light vibrating in all but certain directions, called privileged directions. Anisotropic crystals were used on old polarizing microscopes (before 1950). **Polaroid** is a plastic film consists of long-chain organic molecules that are aligned in one direction. They are placed close enough to form a closely spaced linear grid that allows the passage of light vibrating only in the same direction as the grid. Light vibrating in all other directions is absorbed. Such a device is also called a polarizer.

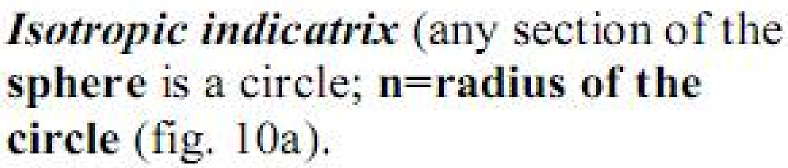
Optical indicatrix

Optical indicatrix is an imaginary geometrical figure which depicts the variation of refractive index of a mineral different in directions (orientations). If we consider an infinite number of vectors radiating from a central point within a mineral, where each vector length is proportional to **n**, the surface connecting the tips of these vectors will represent the optical indicatrix.

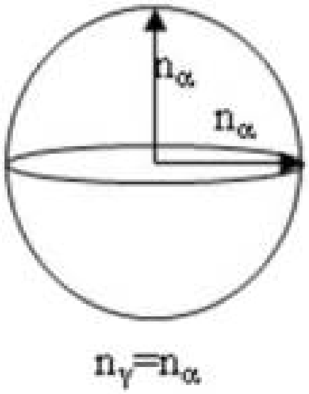
1- Indicatrix of cubic minerals (Isotropic indicatrix):

In minerals of the cubic system (isotropic), where **n** (refractive index) has the same value in any direction, all of the vectors (radiating from a central point in the mineral) would have the same length, and consequently their indicatrix will describe a sphere). In these cubic minerals, (e. g., garnet, spinel, sodaliteetc), all possible sections through a cubic crystal produce ***a circular indicatrix section***.

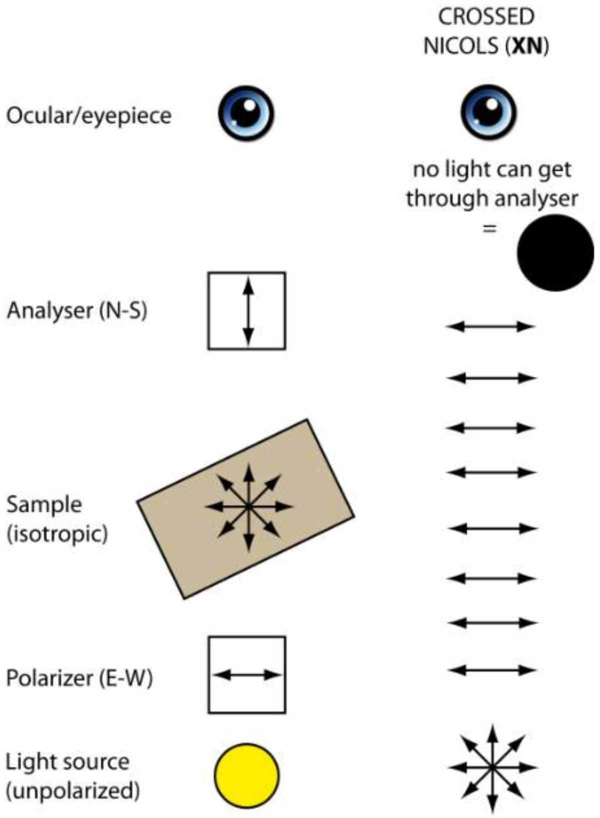




Isotropic indicatrix (any section of the **sphere** is a circle; **n=radius of the circle** (fig. 10a).



Isotropic indicatrix



CROSSED NICOLS (**XN**)

Ocular/eyepiece

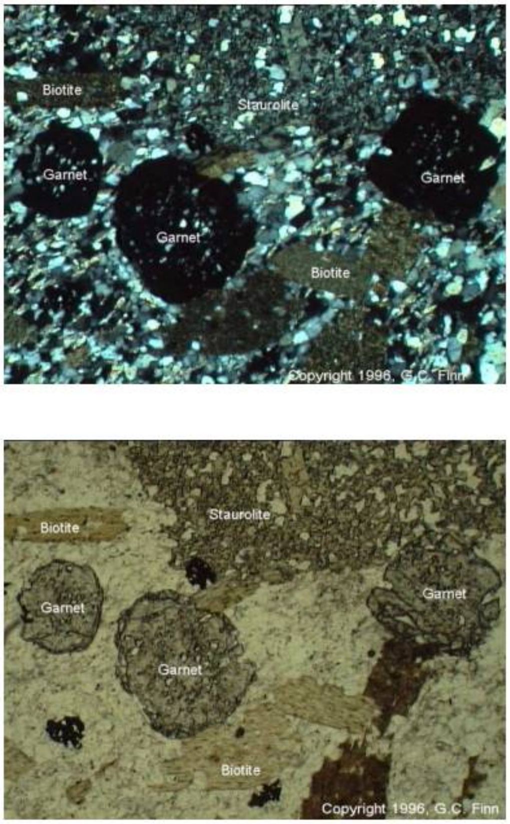
no light can get through analyser =

Analyser (N-S)

Sample (isotropic)

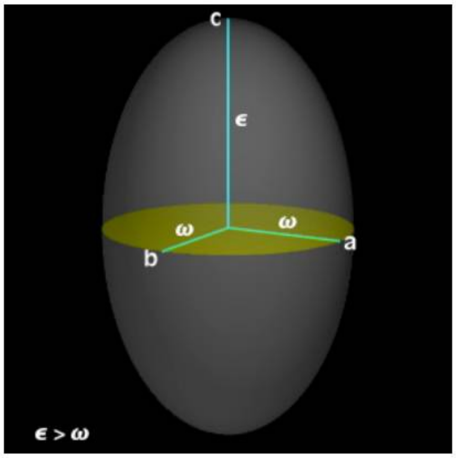
Polarizer (E-W)

Light source (unpolarized)

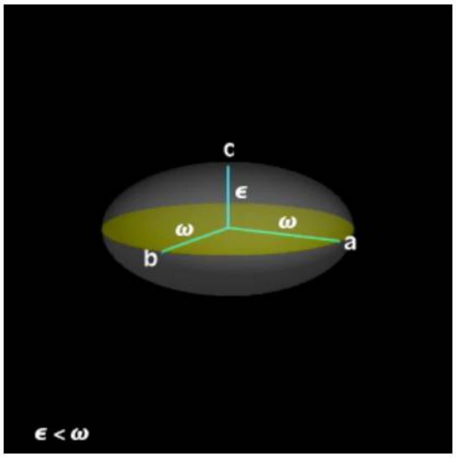


2- Indicatrix of tetragonal, hexagonal and trigonal minerals (uniaxialindicatrix):

In these minerals (e. g., quartz, calcite, apatite etc..), **n** varies continuously from a minimum value n_o (also labeled n_ω or n_α) to a maximum value n_e (also labled n_ε or n_γ). The uniaxial indicatrix has the shape of an ellipsoid, where the long axis is n_ε (n_γ) and the short axis is n_ω (n_α). two specific sections of the indicatrix are important for making the connection to the symmetry of the mineral: a) the section that contains both maximum and minimum values of **RI** (n_γ, n_α respectively) which is called section of maximum birefringence and b) the sections with a circular shape (called the isotropic section). The perpendicular direction on such sections is called optical axis (or direction of monorefringence).



B. The indicatrix is positive if $\varepsilon > \omega$.

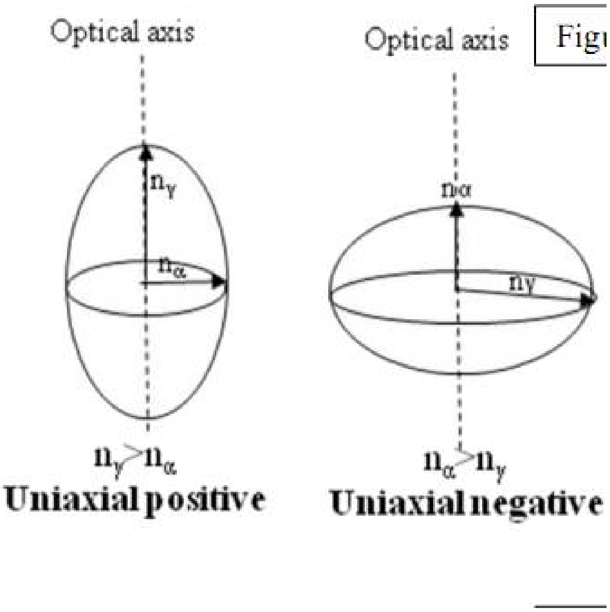


C. The indicatrix is negative if $\varepsilon < \omega$.

Uniaxial indicatrix
(revolution/rotation ellipsoid).

the direction perpendicular to circle section is called the *optic axis*.

- → If the **optic axis** is parallel to (contains) the maximum R.I., **nγ**, then it is a **positive** uniaxial indicatrix (a **rugby ball** shape, positioned for a penalty kick).
- → If the optical axis is parallel to (contains) the minimum R.I., **nα**, then it is a **negative** uniaxial indicatrix (a rugby ball being passed?).

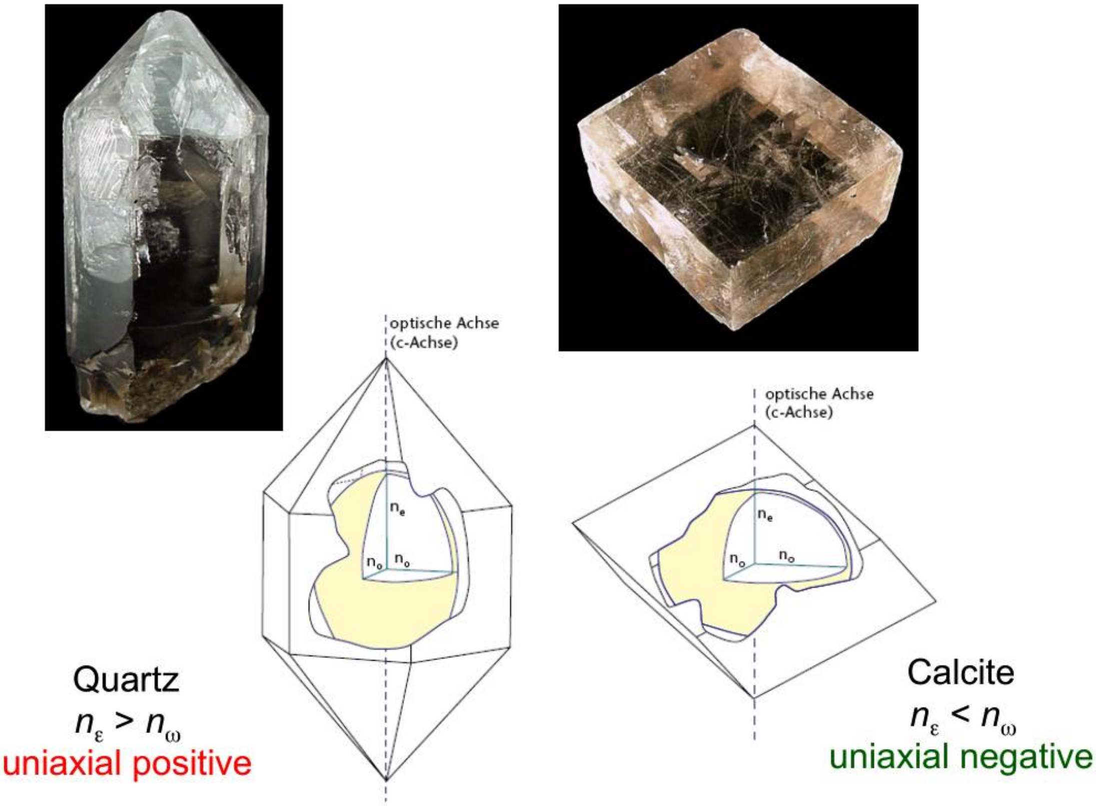


$n_\gamma > n_\alpha$
Uniaxial positive

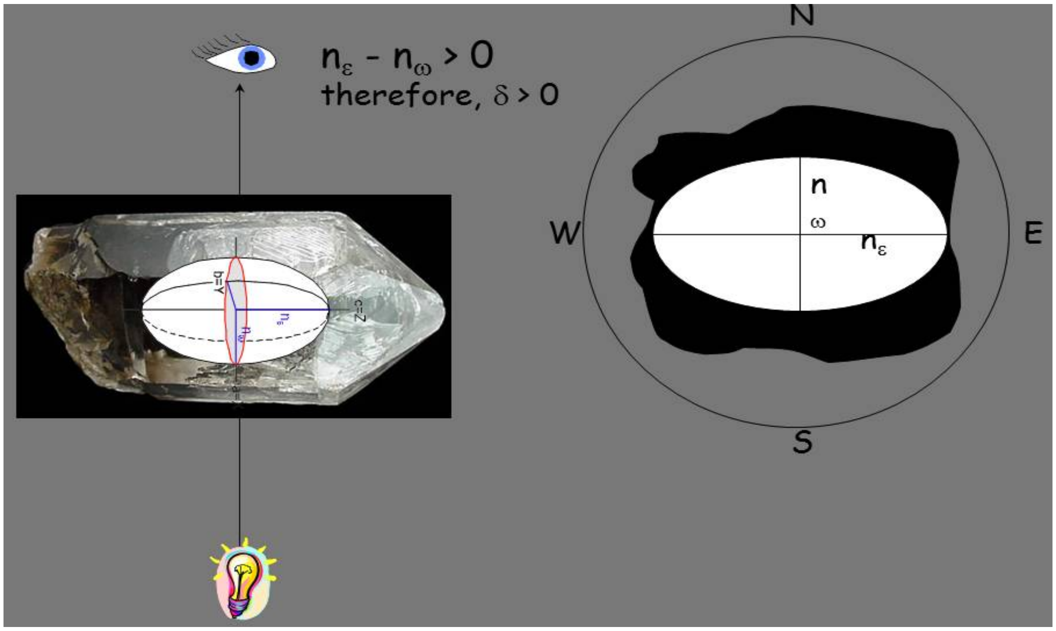
$n_\alpha > n_\gamma$
Uniaxial negative

Example:

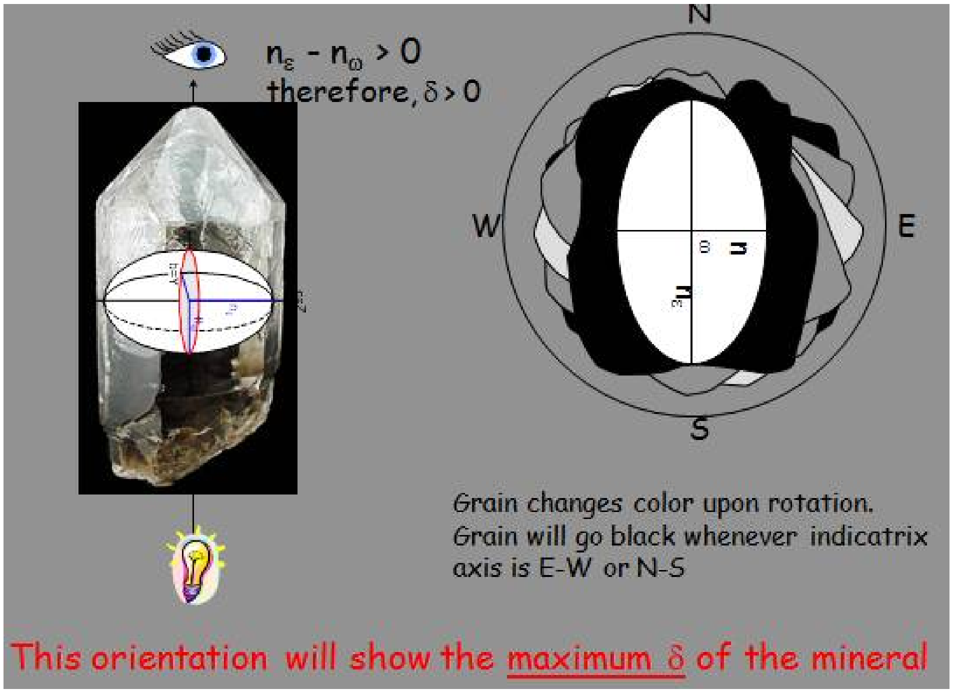
quartz is uniaxial (+) Calcite is Uniaxial (-)



When the mineral is cut through these two sections, it appears extinguished in crossed nicols.

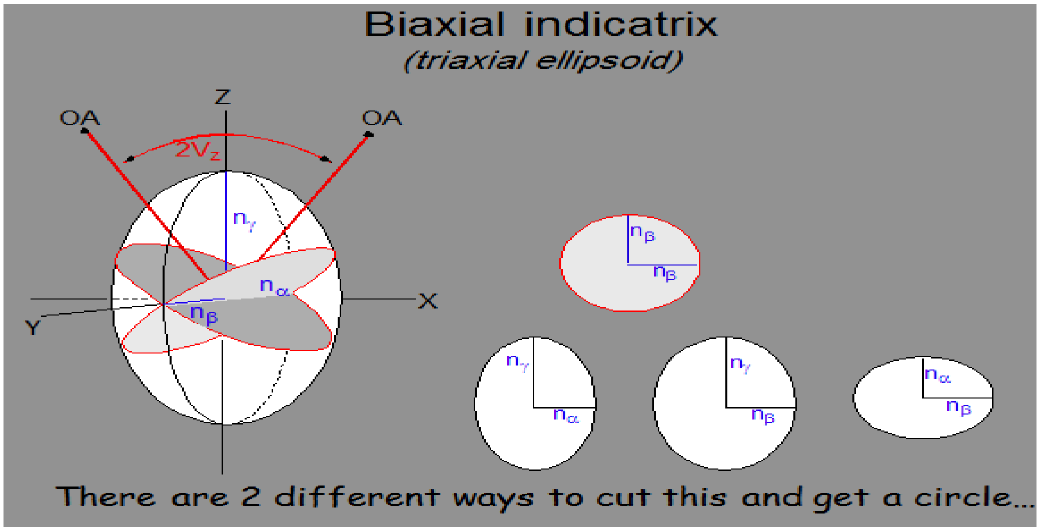


Any random section away from those two section, the mineral is lighted with a color different from its original color.



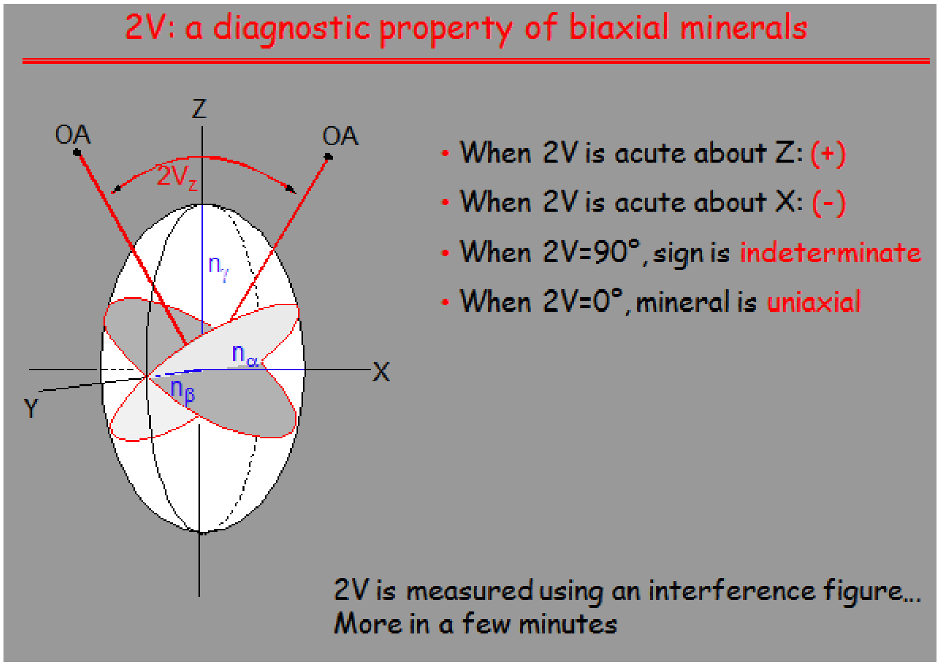
3- Indicatrix of Orthorhombic, monoclinic and triclinic minerals (Biaxial indicatrix):

In these minerals (augite, hornblende, biotite, etc..), **n** varies continuously from a minimum (lowest) value n_α with horizontal direction x, (also labled n_x) through an intermediate value n_β with horizontal direction y (also labled n_y) to a maximum value n_γ with direction z (also labled n_z). The biaxial indicatrix takes the shape of flattened ellipsoid, where the long axis is n_γ or n_z intermediate axis is n_β or n_y and the short one is n_α or n_x. The biaxial indicatrix has two ***circular sections*** and two optical axes (OA) perpendicular to them (i.e., or has two directions of monorefringence & two optic axes right to them).



X direction = n_α (lowest)
Y direction = n_β (intermed; radius of circ. section)
Z direction = n_γ (highest)

- Orthorhombic: axes of indicatrix coincide w/ xtl axes
- Monoclinic: Y axis coincides w/ one xtl axis
- Triclinic: none of the indicatrix axes coincide w/ xtl axes



2V: a diagnostic property of biaxial minerals

- When 2V is acute about Z: (+)
- When 2V is acute about X: (-)
- When 2V=90°, sign is indeterminate
- When 2V=0°, mineral is uniaxial

2V is measured using an interference figure…
More in a few minutes

The two optic axes (OA)$_s$ lie in the plane of the biaxial indicatrix containing n_α and n_γ semi-axes. This plane is called the optic axial plane (OAP). The smaller angle between the two optic axes (OA)$_s$ is known as the optic axial angle (2V).

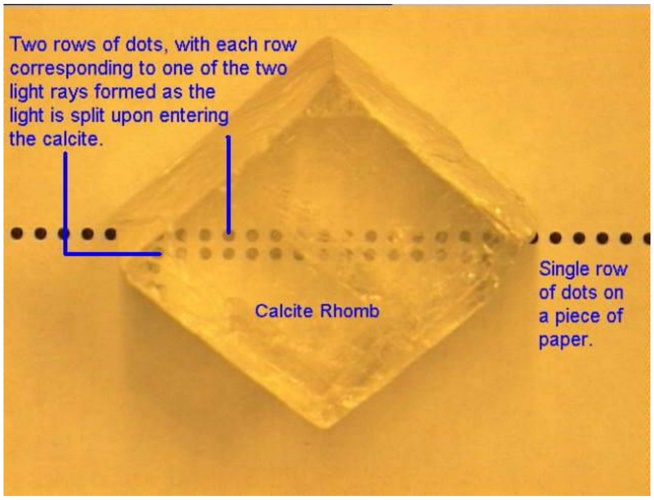
The semi-axis which bisects the 2V is called the acute bisectrix (Bxa). If n_γ is the BXa, then the mineral is biaxial positive (+)ve. When n_α is the BXa, then the mineral is biaxial negative (-)ve.

DOUBLE REFRACTION:

When light travels through anisotropic minerals (away from privilege directions), it splits into two rays which vibrate at right angles to each other. These two rays are corresponding to two axes of the optical indicatrix of the uniaxial minerals n_α ($n_{o \text{ or }} n_\omega$) and n_γ (n_e or n_ε) and any two of the three axes of optical indicatrix of the biaxial minerals n_α (n_x), n_β (n_y) and n_γ (n_z).

Famous example to recognize double refraction phenomenon:

Light travelling through the calcite rhomb is split into two rays which vibrate at right angles to each other. Each ray produces an images as in the following figure:

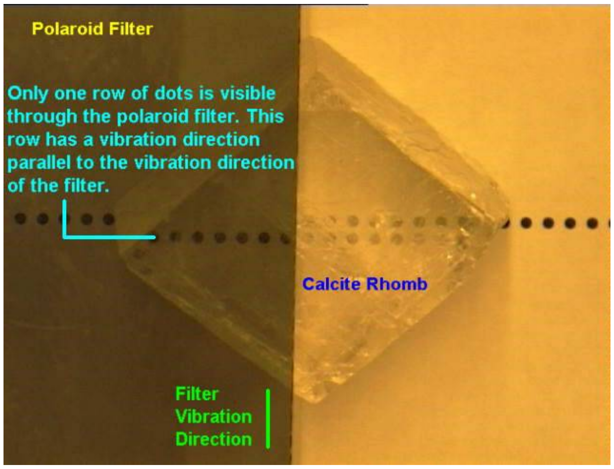


The two rays and the corresponding images produced by the two rays are apparent in the above image. The two rays are:

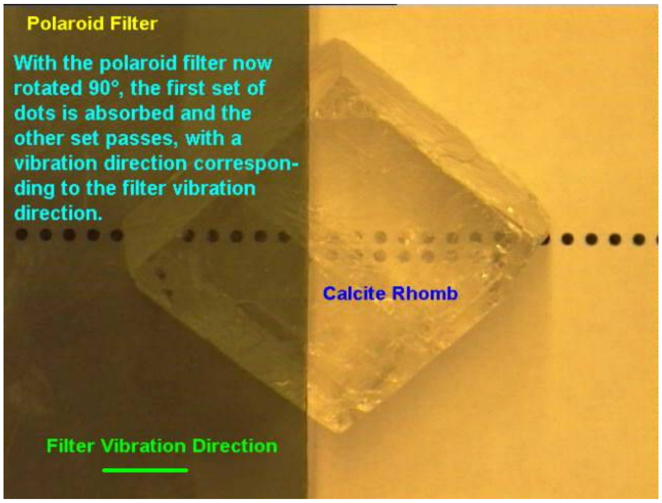
1. Ordinary (slow) Ray, n_α ($n_{o \text{ or }} n_\omega$) = 1.658

2. Extraordinary (fast) Ray, n_γ (n_e or n_ε) = 1.486.

If we used a filter polaroid film of Preferred Vibration Direction **NS**, only one row of dots will be visible because it corresponds to the light ray which has a vibration direction parallel to the filter's one, while the other row is absorbed by the filter.



With the polaroid filter in the **EW** orientation, again only the other row of dots that is not observed in the previous image will be seen.



Why double refraction in anisotropic minerals??

In anisotropic minerals there are:

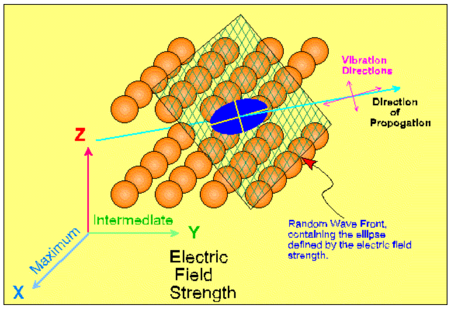
1. Different strength of chemical bonds and atom density in different directions.
2. Different electronic arrangement depending on the different directions
3. Different resonant frequencies of vibration of the electron clouds around each atom in different directions.

Velocity of light in these minerals depends on the interaction between the vibration direction of the **electric vector of the light** and the **resonant frequency of the electron clouds** in the mineral Resulting in the variation in velocity with direction.

Different packing leads to different **electric field strength** around each atom, being minimum, intermediate and maximum in different directions.

Result is that the electronic field strengths within the plane of the wavefront define an ellipse whose axes are;

1. at 90° to each other,
2. represent maximum and minimum **electronic field strengths**, and
3. correspond to the vibration directions of the two resulting rays.



Study of Light Under Plane Polarized light (PPL):

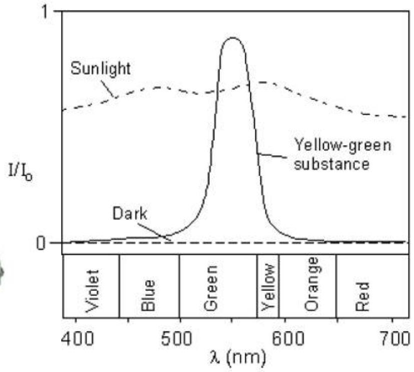
This comprises:

1- **Color**:

Minerals range from colorless (none of wavelengths of white light is absorbed) to opaque (all of wavelengths are absorbed). When light enters a transparent material some of its energy is dissipated as heat energy (absorption property), and it thus loses some of its intensity. When *selective absorption of wavelengths takes place by the mineral*, the appeared color represents a combination of the rest transmitted ones.

Example: In a green mineral (e.g. hornblende), Red/orange and blue/violet wavelengths are absorbed, and the mineral remains transparent only for green light.

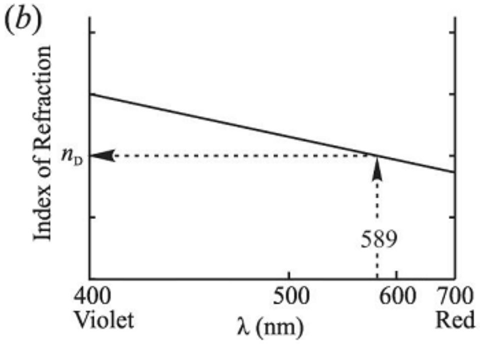
absorption curve If we measure the intensity of light, I_o , for each wavelength before it is transmitted through a mineral, and measure the intensity I for each wavelength after it has passed through the mineral, and plot I_o/I versus wavelength we obtain the absorption curve for that mineral. The absorption curve (continuous line) for the material in this example shows that the light exiting the hornblende will have a yellow-green color, called the absorption color.

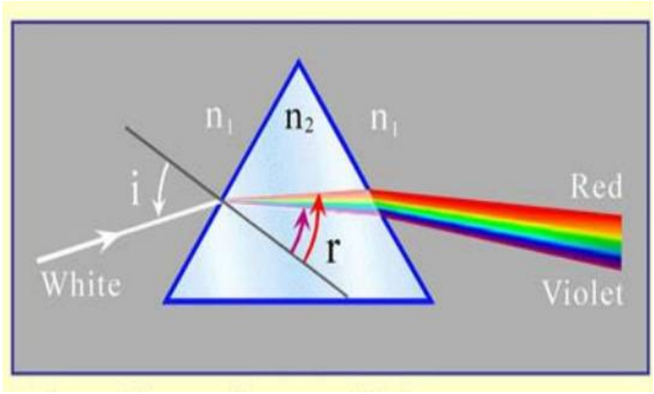


Hornblende in hand specimen   Absorption curve of hornblende   Hornblende.

$$n_{red}<n_{orange}<n_{yellow}<n_{green}<n_{blue}<n_{violet}$$

$$r_{red}>r_{orange}>r_{yellow}>r_{green}>r_{blue}>r_{violet}$$





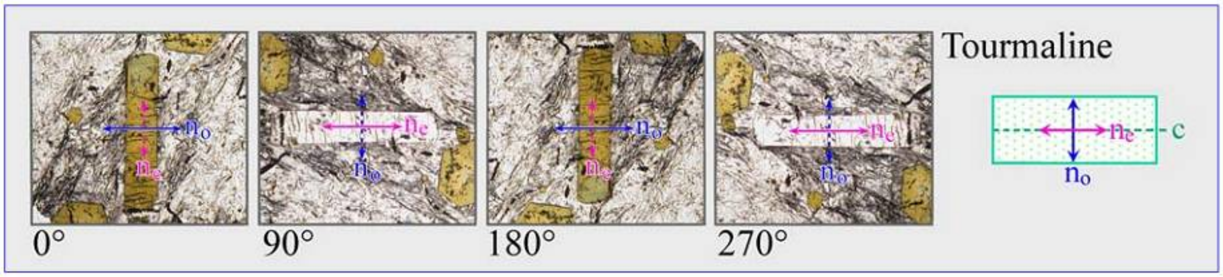
2- Pleochroism:

Pleochroism is the change of the mineral color between two extremes with the rotation of the microscope stage, twice upon a complete rotation (360°).

This is because the unequal absorption of light by the mineral in different directions.

Cubic minerals show no pleochroism, uniaxial minerals (tetragonal, hexagonal and trigonal) show two colors, while biaxial ones (orthorhombic, monoclinic and triclinic) can show three colors coinciding with the three axes of their optical indicatri .

Example: of pleochroism in uniaxial minerals (tourmaline)



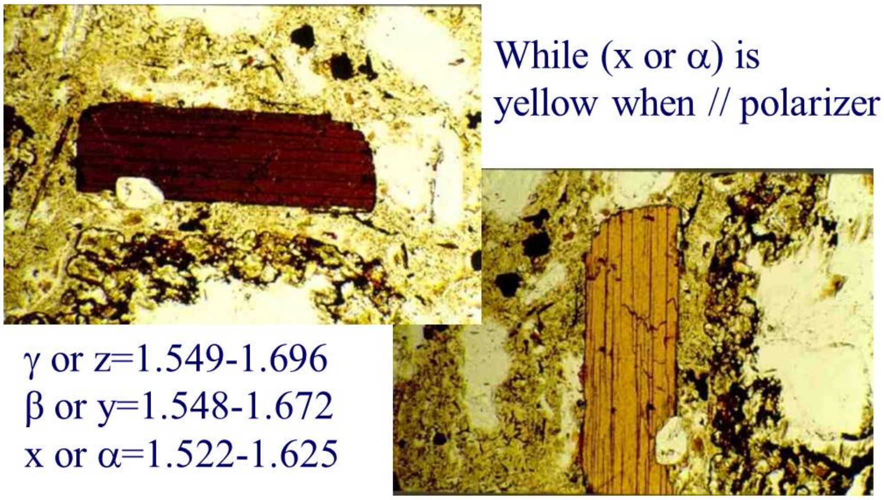
Tourmaline (trigonal system) .

n_ω =1.610-1.630 ⇨ Brown or green

n_ε =1.635-1.655 ⇨ colorless or yellow

Color and pleochroism in biotite

*(β or y) and (γ or z) are dark brown when // polarizer



While (x or α) is
yellow when // polarizer

γ or z=1.549-1.696
β or y=1.548-1.672
x or α=1.522-1.625

3- <u>Crystal form</u>

When the crystal is surrounded by all its crystal faces the crystal then is said to be **euhedral,** when it is surrounded by some of its crystal faces it is said to be **subhedral,** and when it hasn't any of its crystal faces, it is then known as anhedral.

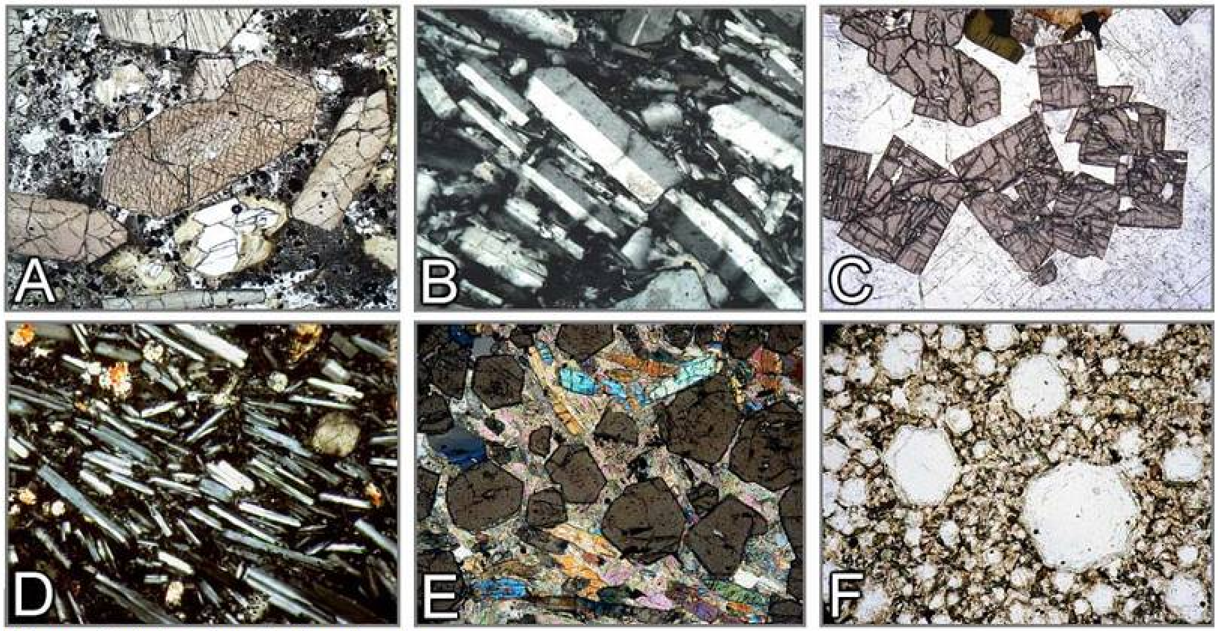


Figure 3.1-4: Euhedral grain shape
A: Augite (basalt), B: Sanidine (trachyte); C: Zircon (syenite pegmatite); D: Plagioclase (basalt); E: Garnet (garnet-kyanite micaschist); F: Leucite (foidite).

Figure 3.1-5: Subhedral grain shape
A: Amphibolite; B: Biotite-muscovite schist; C: Olivine in basalt

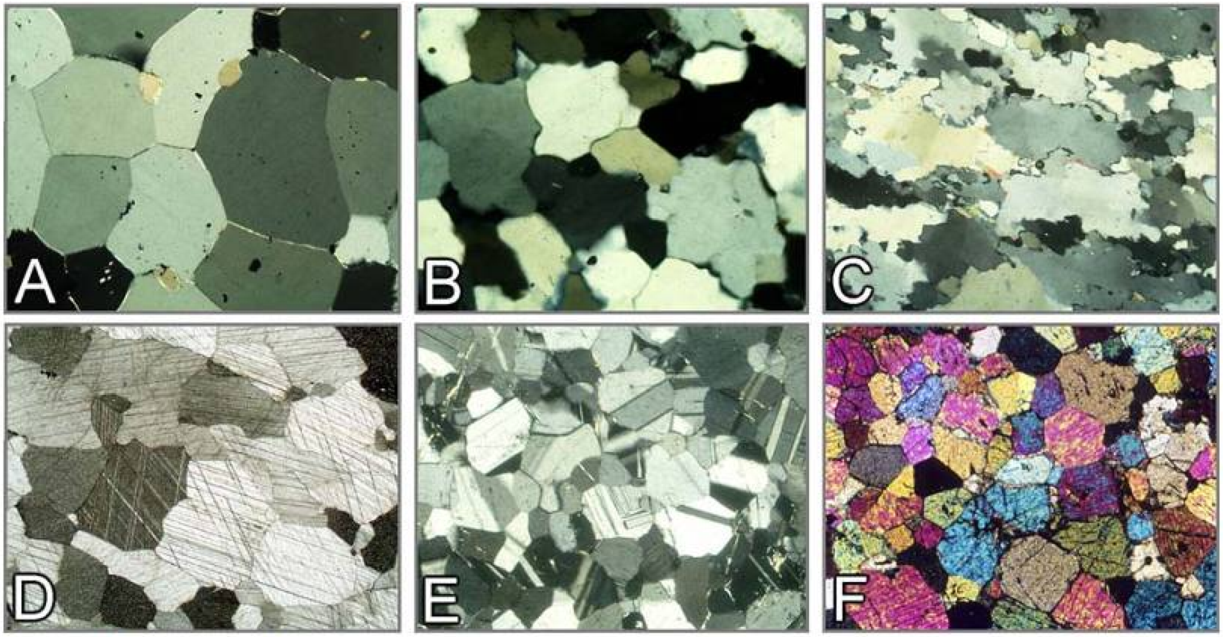


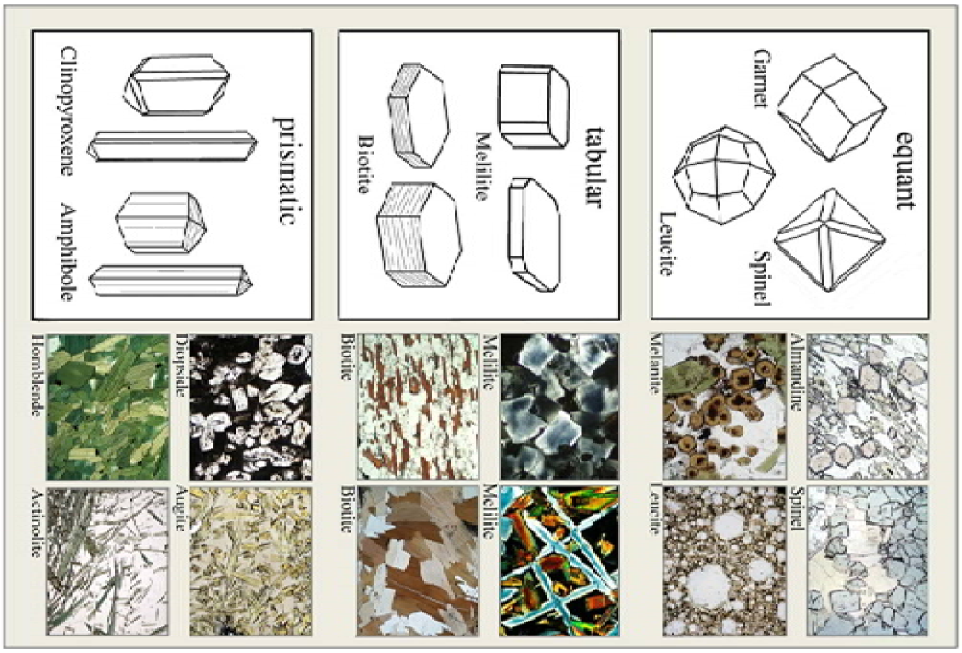
Figure 3.1-6: Anhedral grain shape
Granoblastic textures of quartzite (A to C), marble (D), anorthosite (E) and fayalite fels (F).

4- Crystal habit:

Crystal habit describes the three dimensional form of the mineral grains. Description of crystal habit needs to search up in the thin section.

Equant, tabular and prismatic are the main crystal habits.

Columnar, lath-shaped, fibrous, acicular, sheaf and rosettes are also known

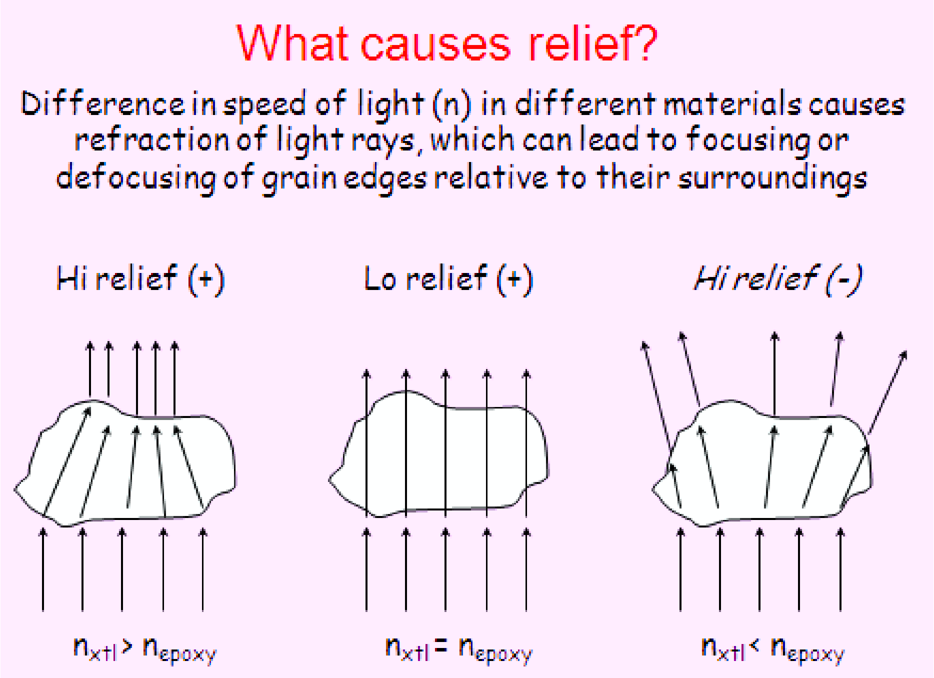


5- <u>Relief and twinkling:</u>

Relief describes the appearance and the visibility of the mineral borders and cleavages (relative to its surroundings).

Relief depends on the difference in refractive index between the mineral and its surroundings.

When the refractive index (**RI**) or **n** of the mineral equals or approaches to that of the surrounding medium, the mineral shows no or low relief. The relief is interpreted according to refraction of light when passes through the interfaces between different media with different refractive indices (snell's law).



What causes relief?

Difference in speed of light (n) in different materials causes refraction of light rays, which can lead to focusing or defocusing of grain edges relative to their surroundings

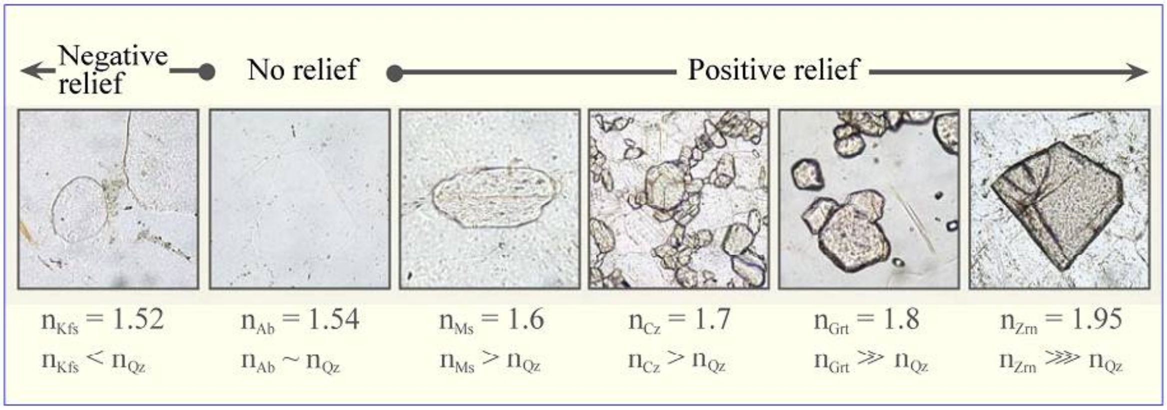
Hi relief (+) | Lo relief (+) | *Hi relief (-)*

$n_{xtl} > n_{epoxy}$ | $n_{xtl} = n_{epoxy}$ | $n_{xtl} < n_{epoxy}$

When there is a difference in **RI** or **n**, the borders appears and it is said that the mineral is high relief.

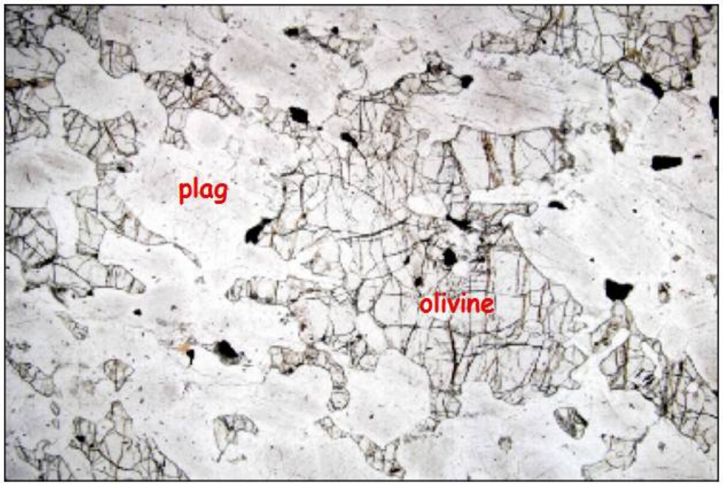
If **RI** of the mineral > that of the surrounding medium→High relief (+)

If **RI** of the mineral < that of the surrounding medium→High relief (-)



Relief of K-feldspar (Kfs), albite (Ab), muscovite (Ms), clinozoisite (Cz), garnet ,Grt) and zircon (Zrn) in quartz (n=1,55).

- Relief is a measure of the **relative** difference in **n** between a mineral grain and its surroundings
- Relief is determined visually, in PPL
- Relief is used to estimate n

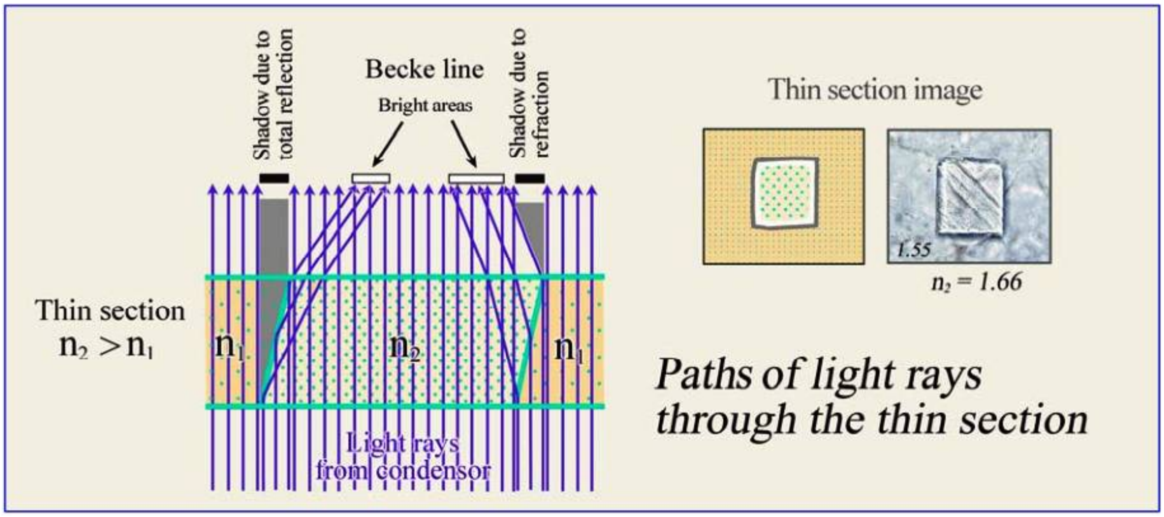


- Olivine has high relief
- Plagioclase has low relief

olivine: n=1.64-1.88
plag: n=1.53-1.57
epoxy: n=1.54

Becke line and Becke method for estimating the relief

The Becke line is a narrow bright line along grain boundaries caused by light refraction and scattering along the crystal surface.



When lowering the rotating stage (using the fine focus), the Becke line migrates into the phase of higher RI (Fig. 23). This is called Becke method and it is a very sensitive method (determines n to ± ~0.02).

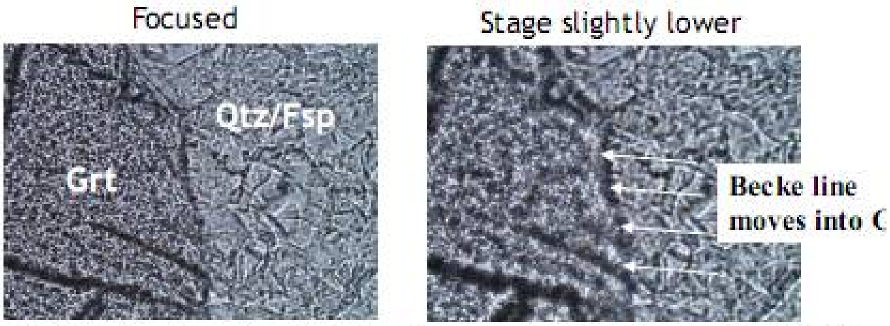
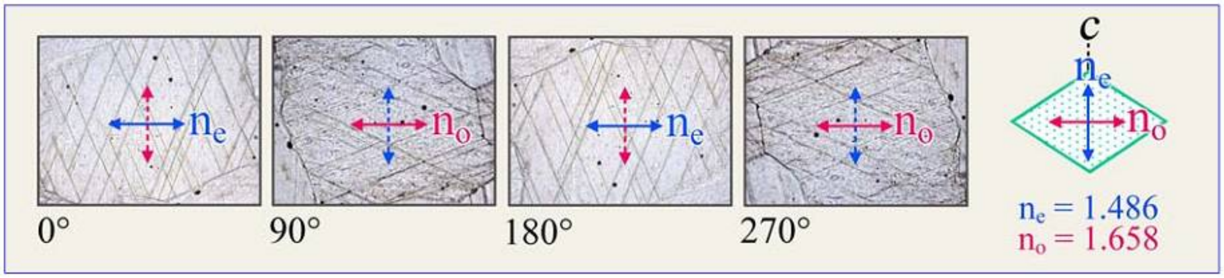

Focused
Stage slightly lower

Figure 23: Becke line observed at the boundary between garnet (Grt) and quartz-feldpar (Qtz/Fsp) aggregate. The Becke line moves into the garnet (into the mineral with higher refractive index) when slightly defocusing the image as the stage is lowered. Note also fine bright lines (also Becke lines) between the quartz and feldspar grains.

Twinkling is the change in relief with the rotation of the microscope stage due in anisotropic minerals due to the variation in the refractive indices of the mineral against the same refractive index of the surrounding medium



6- **Cleavage**:

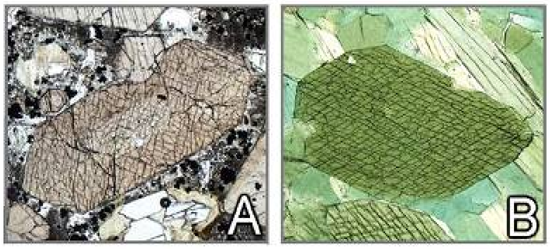
In thin sections, cleavage is recognized as parallel straight traces of planes dissecting the grain in a certain direction, which is called a set of cleavage.

Some minerals has no cleavage at all, others have one set of cleavage, e. g., mica minerals, two sets of cleavage e. g., pyroxenes and amphiboles, ans some minerals have three sets, four sets, … etc.

Figure 3.2-1: Cleavage

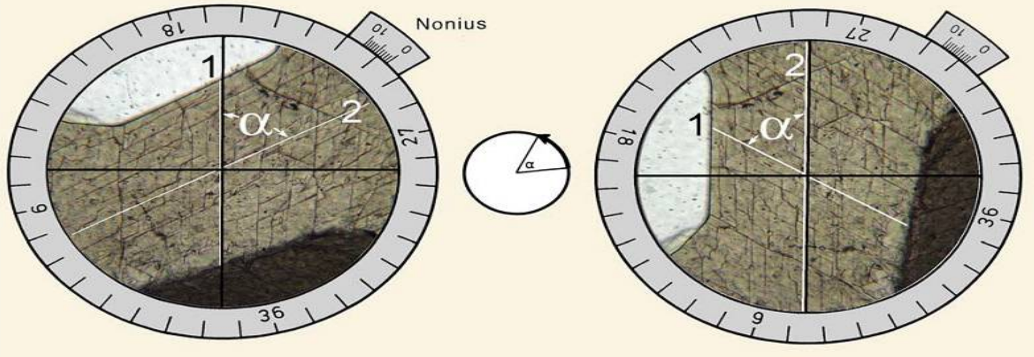
A. Augite: Section orthogonal to c axis. The {110} cleavage planes form angles of 87° and 93°.

B. Hornblende: Section orthogonal to c axis. The {110} cleavage planes form angles of 56° and 124°.



Measurment of cleavage angle:

In minerals with two sets of cleavages, we need to measure the cleavage angle (α) to differentiate between minerals or mineral groups. We adjust one of the two sets with one of the crossed hairs and take the reading of the stage vernier, then we bring the other set with the same hair and take the difference to get α.



Stage position I = 243.0° Stage position II = 302.0°

Cleavage intersection angle α = I-II = 59.0°

7-Inclusions: comprise smaller minerals or fluid pebbles enclosed within the mineral.

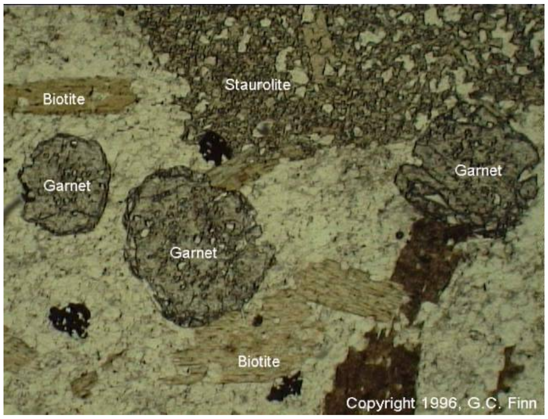
8-**Alterations**: some mineral weather into other minerals.

2-Stusy of minerals under crossed nicols:

When the analyzer in entered in the field of view, the mineral grain will behave one of two main behaviors:

1- Extinguishes and still in extinction with rotation of the stage.

In this case, the crystal (garnet for example) is **isotropic** , or may be isotropic section in anisotropic mineral.



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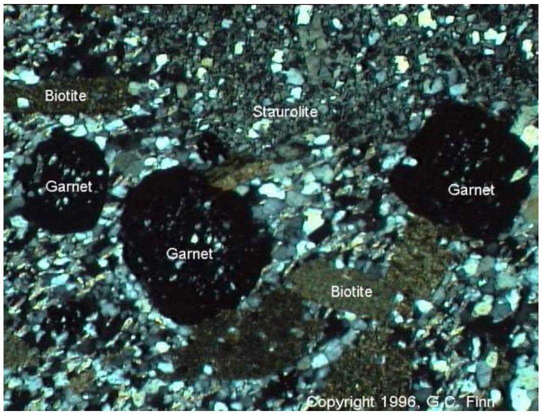

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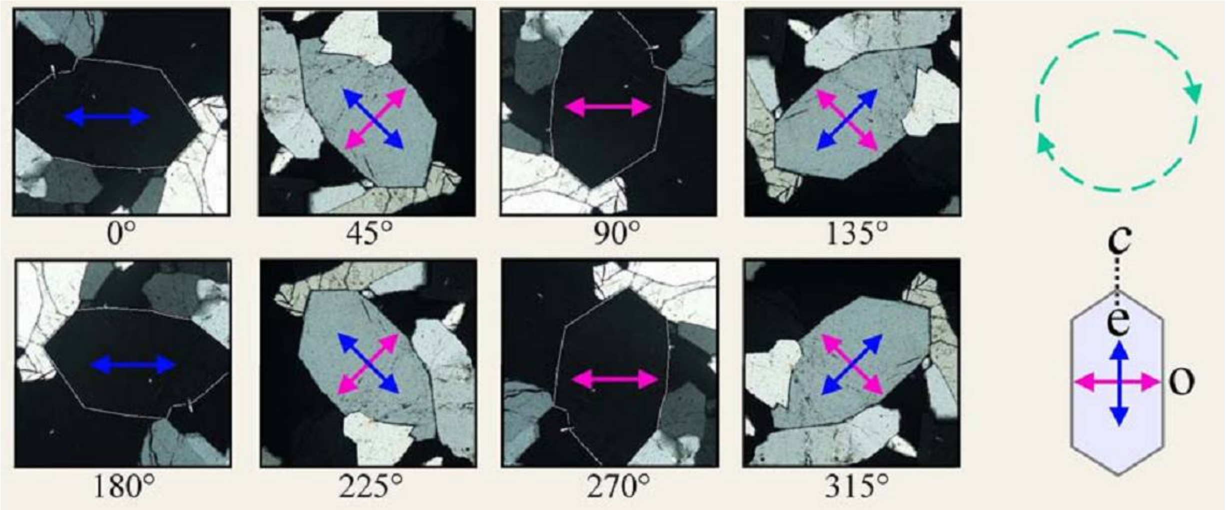
(a) Garnet crystals (cubic system) under PPL

(b) (a) Garnet crystals (cubic system) under CN

2-Extinguishes and illuminates alternatively 4 times over 360° of rotation.

In this case, the crystal is surely anisotropic, but it will give either **parallel extinction** or **oblique extinction.**

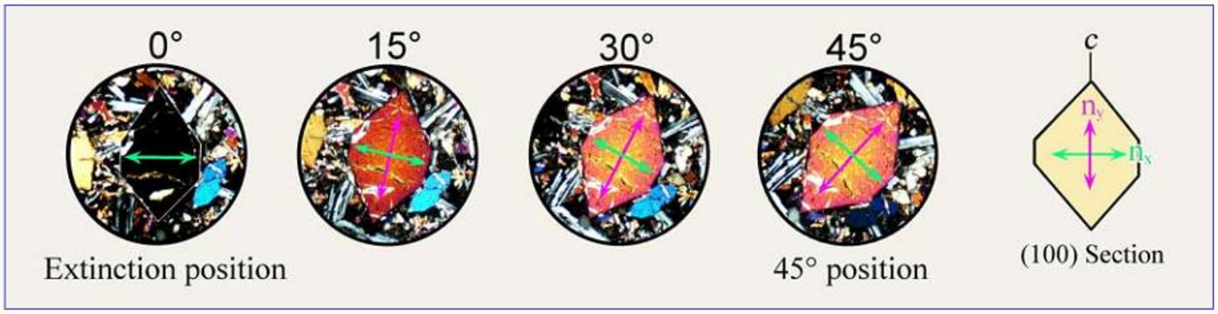
In the **parallel extinction,** the crystals extinguish when crystallographic orientations are adjusted parallel to the cross hairs (directions of polarizer and analyzer). This takes place in the mineral crystals of tetragonal, hexagonal, trigonal and orthorhombic systems. Parallel extinction happens due to the coincidence of the crystallographic axes (a, b, c) of the mineral crystal with their corresponding axes of the optical indicatrix n_α,n_β,n_γ. Accordingly, when the polarized light coming from polarizer passes in _these directions_, it passes in the crystal without splitting and goes up to the analyzer that obscures light from reaching the eye because of its vibration direction that is perpendicular to that of the polarizer.



Extinction positions and diagonal positions of a quartz grain during a 360° rotation of the stage.

In the ***Oblique extinction*,** when crystallographic orientations are adjusted parallel to the cross hairs (directions of polarizer and analyzer), the crystals show illumination with colours different from their original colours. These colours are known as interference colours. This takes place in the mineral crystals of monoclinic and triclinic systems. Oblique extinction happens because the crystallographic axes (a, b, c) of the crystal are not coincided with their corresponding axes of the optical indicatrix n_α,n_β,n_γ. The crystals of those systems extinguish upon rotation of the microscope stage for a while such that the crystallographic axes and the axes of the optical indecatrix are coincided. The angle between the direction of the crystallographic axis and the corresponding axis of the optical indicatrix is called the direction the ***extinction angle*** in that direction.

Accordingly, when the polarized light coming from polarizer passes away from the *__directions__* of n_α,n_β,n_γ, it splits into two perpendicular polarized that go up with two different velocities to the analyzer that in turn splits each of them into two polarized rays, one - of each pair - vibrates with its direction and the other is obscured. The two rays vibrating with the analyzer are interfered giving rise to the interference colours.



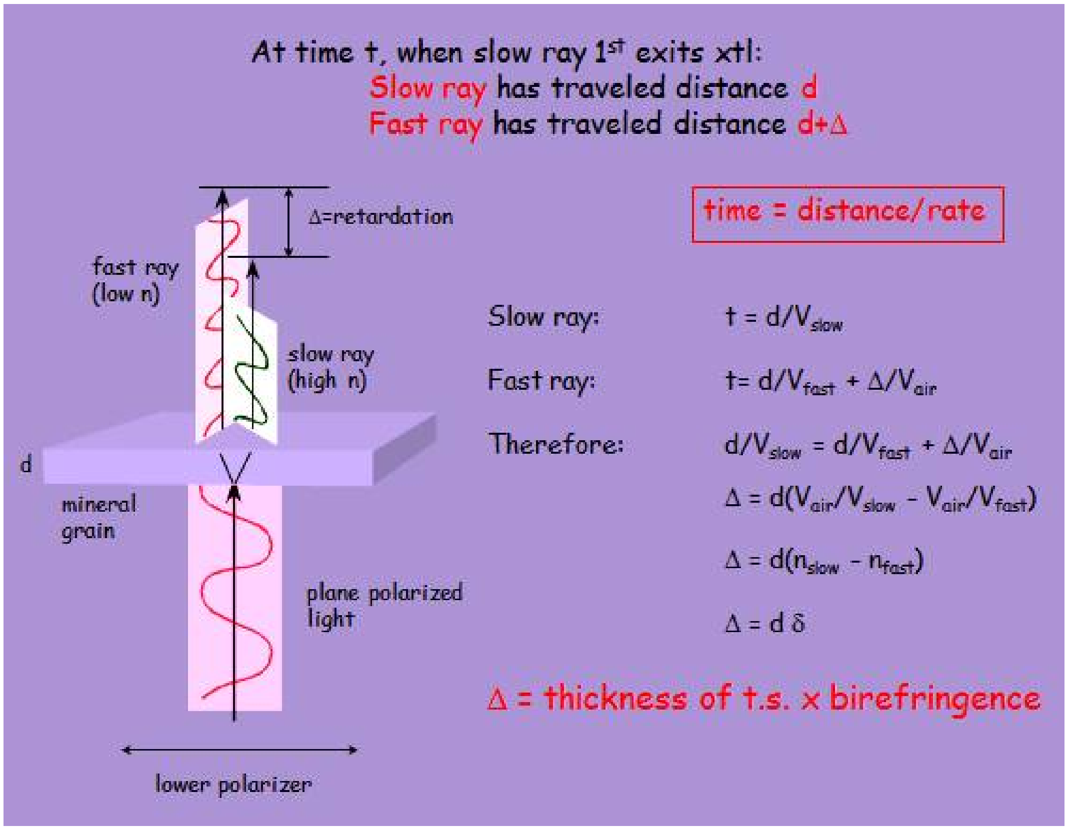
Interference colour of a forsterite crystal as the stage is rotated from the extinction position into a 45° diagonal position. The interference colour does not change, but its intensity does.

Birefrengence and interference colours:

In anisoptopic minerals, a ray of polarized light splits into two perpendicular polarized rays with different velocities:

The faster ray (with velocity V_{fast}) called ordinary ray with lower refractive index ($n_\alpha = n_\omega = n_o$).

The slower ray (with velocity V_{slow}) called extraordinary (with higher refractive index $n_\gamma = n_\varepsilon = n_e$).



At time t, when slow ray 1^{st} exits xtl:

Slow ray has traveled distance d

Fast ray has traveled distance d+Δ

time = distance/rate

Slow ray: $t = d/V_{slow}$

Fast ray: $t = d/V_{fast} + \Delta/V_{air}$

Therefore: $d/V_{slow} = d/V_{fast} + \Delta/V_{air}$

$\Delta = d(V_{air}/V_{slow} - V_{air}/V_{fast})$

$\Delta = d(n_{slow} - n_{fast})$

$\Delta = d\,\delta$

Δ = thickness of t.s. x birefringence

Delay of the slow ray is called retardation and depends on thickness of slide and the difference between n_α and n_γ (**Birefringence)**. Birefringence is expressed in the interference colours.

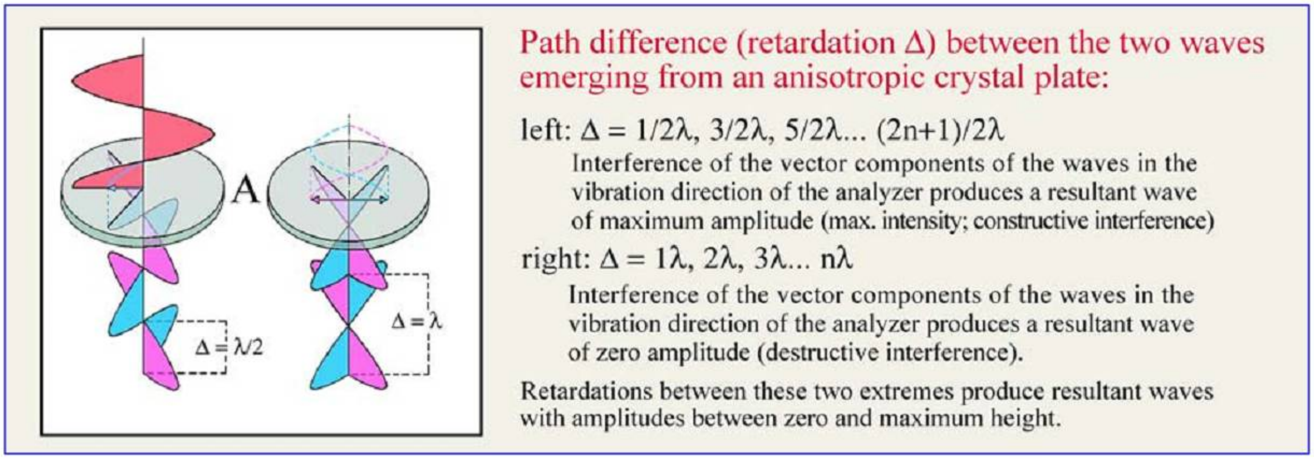
Birefringence $\delta = n_\gamma - n_\alpha = \Delta/d$

In anisotropic minerals,

Constructive interference takes place when $\Delta = (2n+1)/2\lambda = (n+1/2\ \lambda)$

Destructive interference takes place when $\Delta = n\lambda$

Remember that the two rays emerging from minerals vibrate at right angles



Path difference (retardation Δ) between the two waves emerging from an anisotropic crystal plate:

left: $\Delta = 1/2\lambda, 3/2\lambda, 5/2\lambda \ldots (2n+1)/2\lambda$

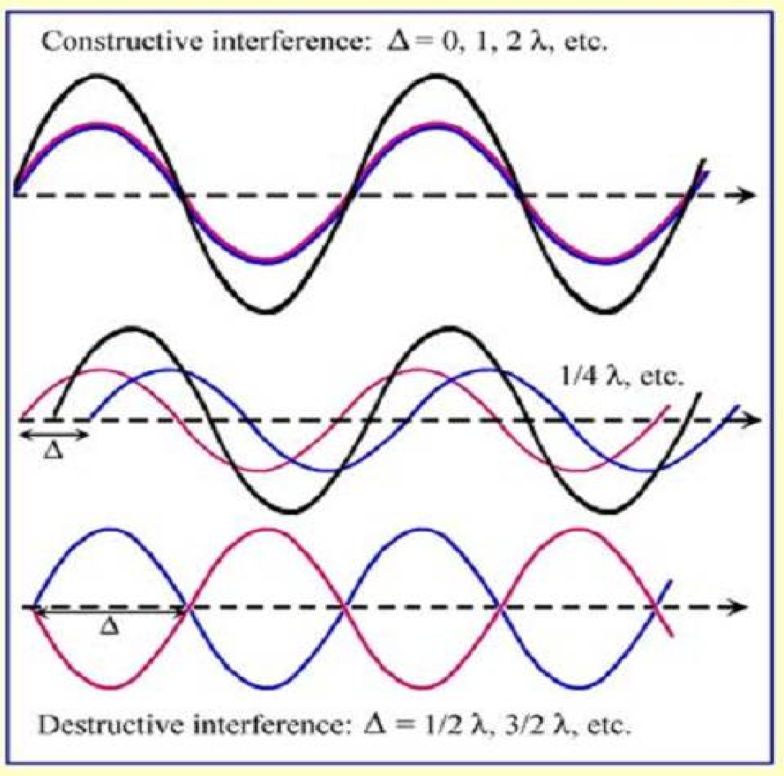
Interference of the vector components of the waves in the vibration direction of the analyzer produces a resultant wave of maximum amplitude (max. intensity; constructive interference)

right: $\Delta = 1\lambda, 2\lambda, 3\lambda \ldots n\lambda$

Interference of the vector components of the waves in the vibration direction of the analyzer produces a resultant wave of zero amplitude (destructive interference).

Retardations between these two extremes produce resultant waves with amplitudes between zero and maximum height.

When the two rays vibrate in the same plane, the rule is conversed

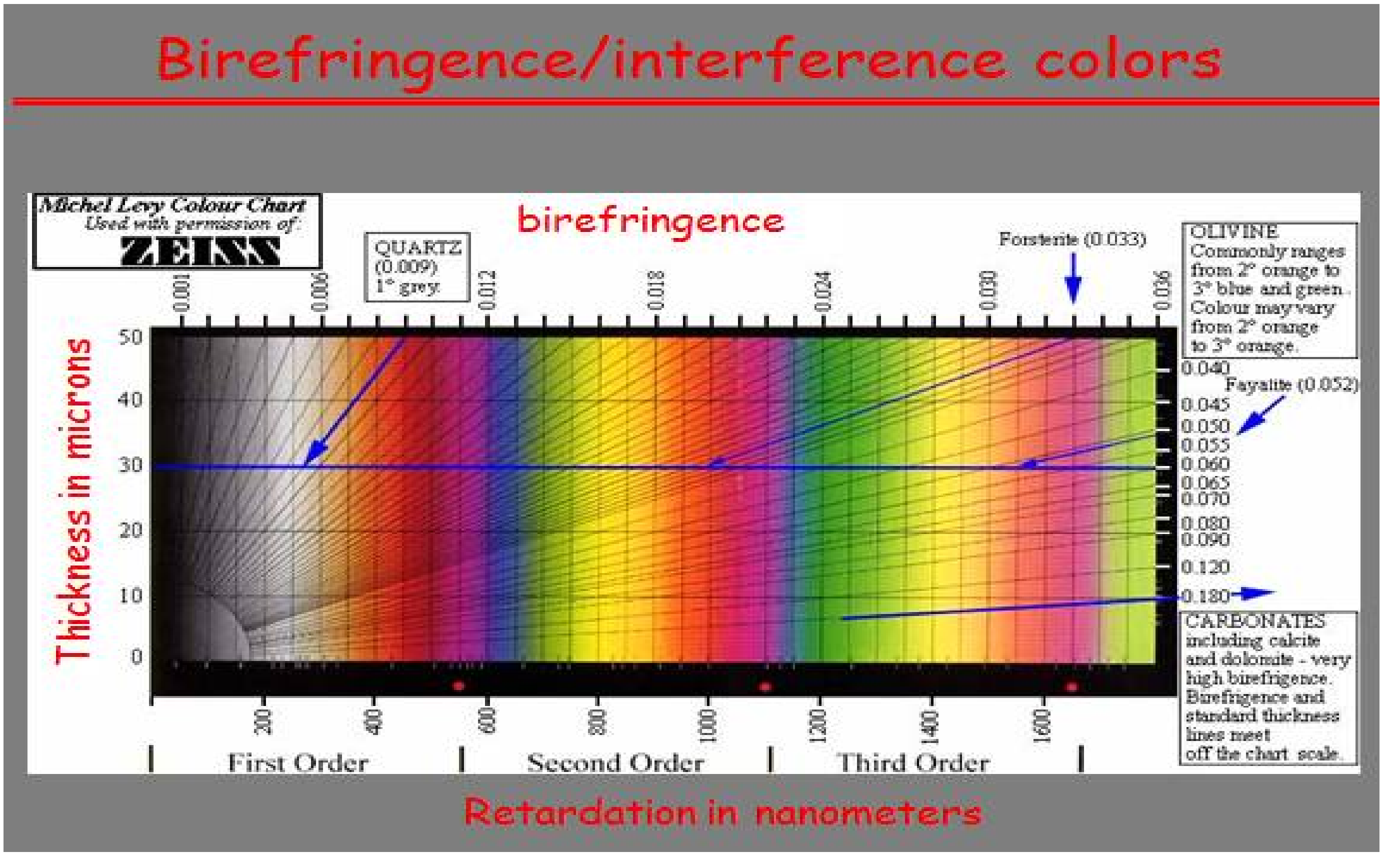

Constructive interference: $\Delta = 0, 1, 2\ \lambda$, etc.

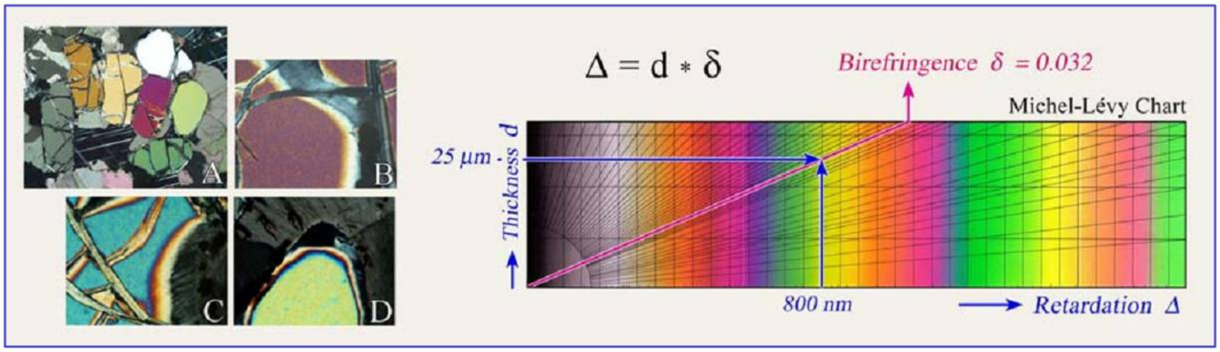
Destructive interference: $\Delta = 1/2\ \lambda, 3/2\ \lambda$, etc.

Birefringence $\delta = n\gamma - n\alpha = \Delta / d$

Graphically, δ is a straight line crossing the origin of graph, in a chart (Michel-Levy chart) where Δ and d are the x and y axes, respectively.

The Michel-Levy chart or table(also known as interference colour chart or birefringence chart) contains 4 orders of colours (each order has a total wavelength of 550 nm). The orders are separated by a violet colour and, as we can see in the chart, as we go to higher retardation (Δ), the colours become more pale and mixed, sometimes difficult to describe.

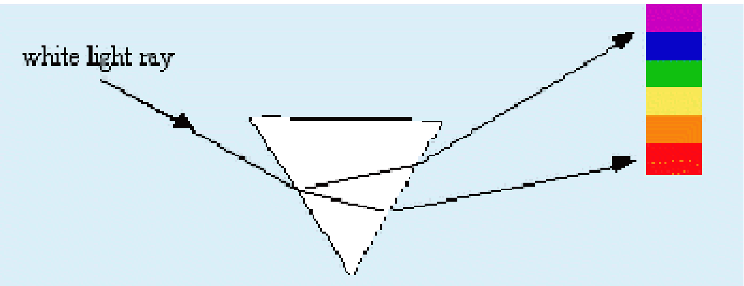




How to establish the order of interference colour??

1- Using the number of isochromates (isochromatic lines and adding 1.

The margins of mineral grains are oblique to light path and act as dispersion prisms



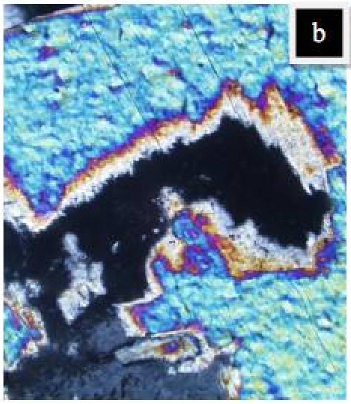
For instance, in a plagioclase with a gray colour of birefringence (no violet isochromates at its boundary). The order of colouris therefore 0+1=1.

In muscovite. The bluish green colour of birefringence is in the second order (we observe one violet isochromate, so the order is 1+1=2).

In calcite with a diffuse, white-greyish colour of birefringence. At its rim, we notice 3 violet isochromates, so the order of birefringence is 3+1=4.

a) 1st order IF colours

b) Isochromates indicate Green 2nd order



c) High order white in calcite

Finding the value of birefringence (δ)

Knowing the thickness of the thin section “d” (which is standard, 30 microns) and observing the birefringence colours in Michel-Levy hart, we can graphically obtain the value of birefringence (values written at the top and right of the Michel-Levy chart) by intersecting theband of the observed colours with the “d” value horizontal line. From that point, going up right on the chart following the line $\delta=\Delta / d$, we get the value of δ (birefringence). For example, the maximum interference colour of quartz is first order white. We look for the intersection of the first order white band in the Michel-Levy table with the horizontal (d) line corresponding to 30 microns thickness. From that point, going up (interpolating between the radiating lines), we get a birefringence value of 0.009, as written at the top of the chart. Looking in the same sample, we will also find grains of quartz with lower birefringence (gray) which means that their orientation is different (the section is not cut parallel to the optic axis, and therefore, our view is not completely perpendicular to the optic axis). If we want to know what maximum color of birefringence to expect from a particular mineral (knowing the value of δ from mineral tables), we go down from the value on the δ line until we intersect the d line. At this intersection we see the color of birefringence that corresponds to a particular δ value.

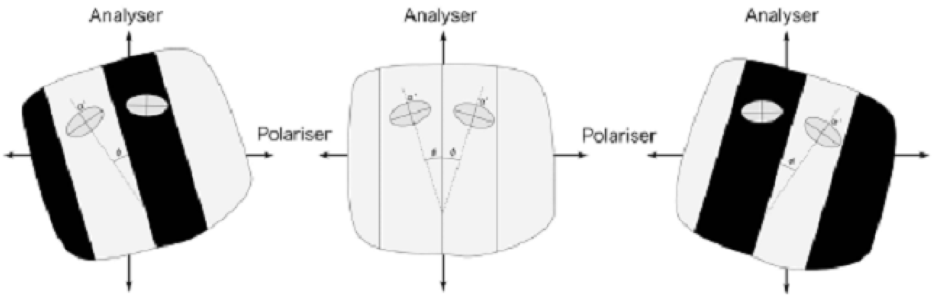
Note that

- The Michel-Levy chart is made for maximum birefringence of minerals, only!! Do not try to memorize a mineral using a specific unique birefringence color. It is pointless and wrong!

Always remember that different colors can be possible for differently-cut orientations.

Interpretation of Twinning (under crossed nicols XPL):

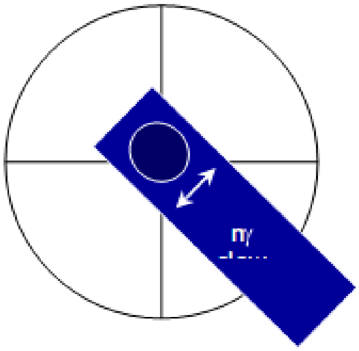
A twin is a symmetrical growth of two or more crystals of the same mineral. The common plane of the twinned crystals (which is called the twinning plane) is a symmetry plane, seen in thin section as a straight line separating two identical crystals (e.g. crystal (1) and crystal (2)) which have a symmetrical optical orientation to the twinning plane, i.e., the indicatrices of the two twinned crystals are symmetrical to the twinning plane. This is observable by rotating the stage (Fig. 32); when crystal (1) is in extinction, its twin crystal (2) shows interference colours. Continuing the rotation of the stage, crystal 1 shows interference colours and crystal (2) will enter into a position of extinction. If the section is cut perpendicular to the twinning plane, the extinction angles of crystal (1) and crystal (2) should be identical (if the crystallographicreference for measuring the extinction is the twinning plane!). If the section cut is not perpendicular to the twinning plane, the extinction angles will be different. If the section is cut parallel to the twinning plane, the twin cannot be observed at all, in the plane of the thin section.



Polysynthetic twins in plagioclase; section ~ perpendicular to the twinning plane (useful for measuring the anorthite content in plagioclase)

Sign of Elongation

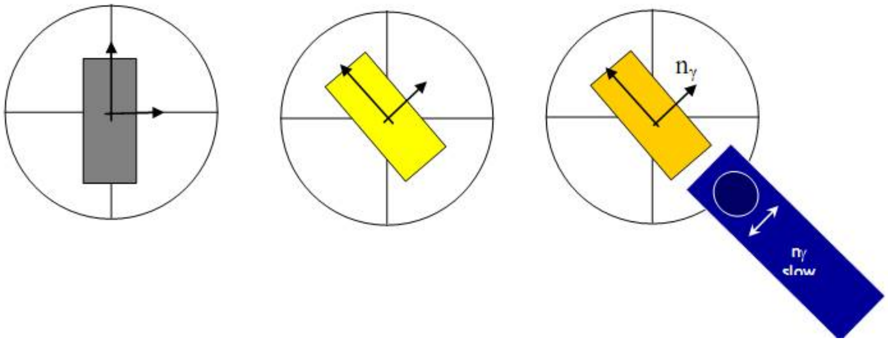
If nγ is parallel to the direction of the longer faces, we say that the crystal has a **positive optical elongation** (the elongation of the optical indicatrix corresponds to the direction of the c axis). This crystal can also be described as “length-slow”. If nα is parallel to the c axis, then the optical elongation is **negative optical elongation**, and the crystal is “length fast”.



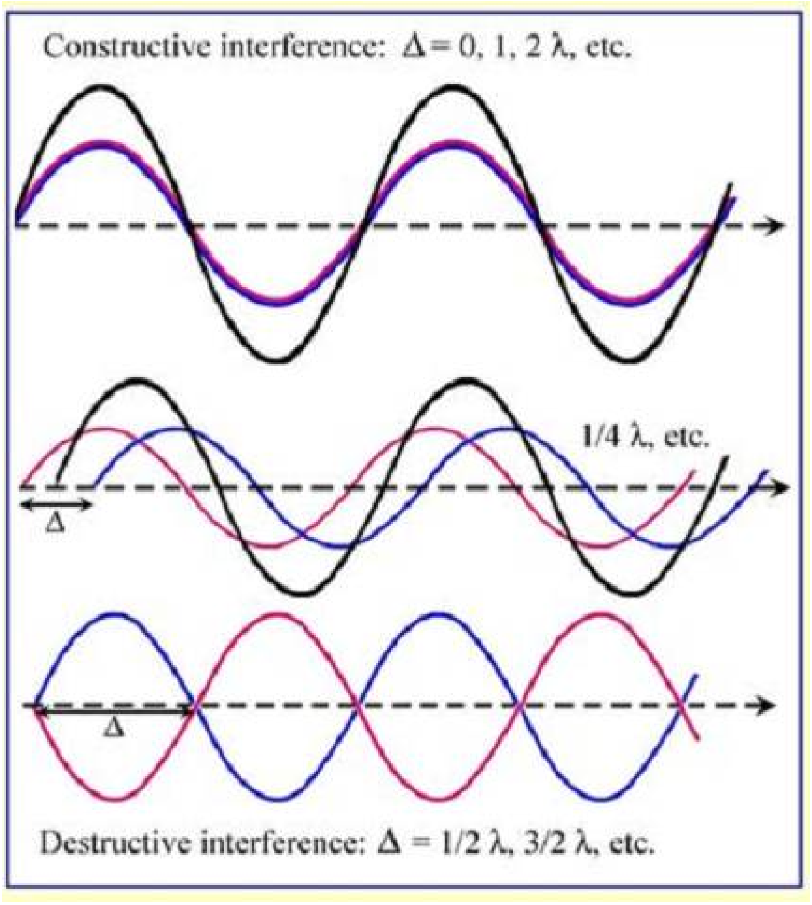
- The wavelength of the λ-plate (gypsum plate with violet interference colour) is 550 nm (~575 nm is the extent of one order in the Michel-Levy table!)

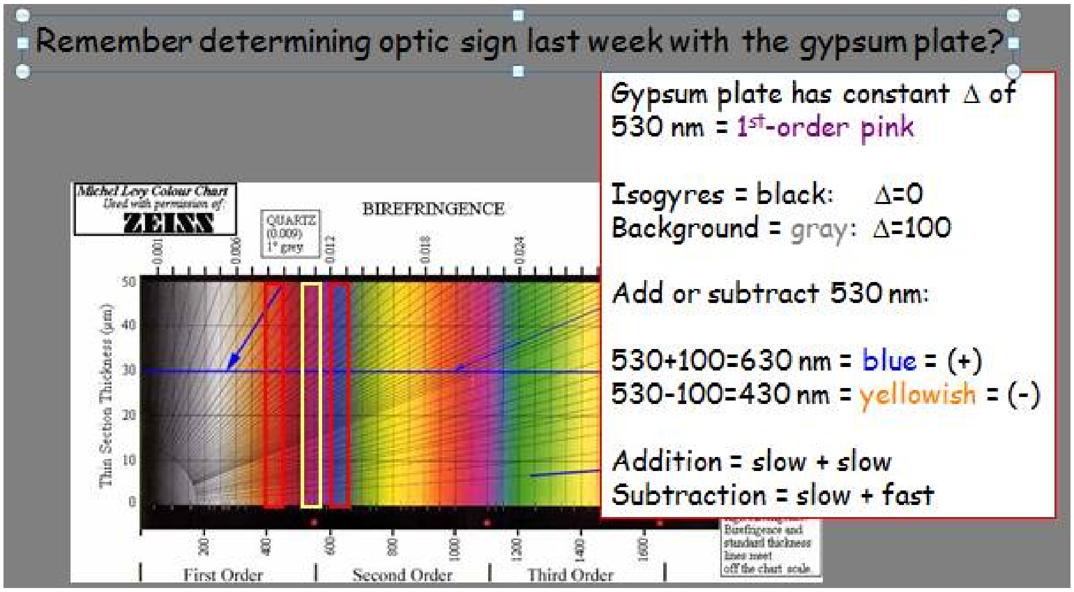
- Adding retardation, will move the colour right in the Michel Levey chart and Vice versa.

colours in the Michel-Levy table (to the left with 550 nm or to the right with 550 nm



Birefringence $\delta = \Delta/d$





Remember determining optic sign last week with the gypsum plate?

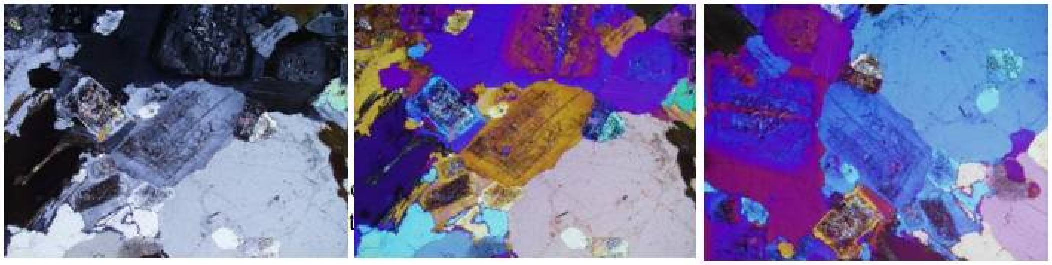
Gypsum plate has constant Δ of 530 nm = 1st-order pink

Isogyres = black: Δ=0
Background = gray: Δ=100

Add or subtract 530 nm:

530+100=630 nm = blue = (+)
530-100=430 nm = yellowish = (-)

Addition = slow + slow
Subtraction = slow + fast



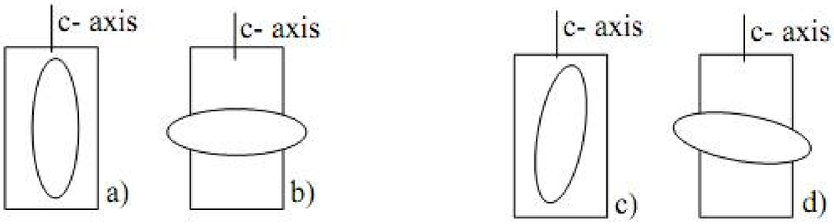


Figure 39: a) parallel extinction, positive optical elongation; b) parallel extinction, negative optical elongation; c) oblique extinction, positive optical elongation; d) oblique extinction, negative optical elongation.

Interference colour of gypsum plate→ violet

Blue→ means increase in retardation i.e. n_γ of gypsum (with known direction NE) coincides with n_γ of the mineral.

Then n_α (small RI) with elongation,

∴ Negative elongation or Length fast

Red/ yellow→ means decrease in retardation i.e. $n\gamma$ of gypsum (with known direction NE) coincides with $n\alpha$ of the mineral.

Then n_γ (high RI) with elongation, ∴ Positive elongation or Length slow

3-Study of minerals under convergent light (Conoscopy).

To distinguish whether an anisotropic mineral is uniaxial or biaxial and for determining the its optic sign, i.e., (+)Ve or (-)Ve. (The interference figure).

To study under convergent light, we need:

1- With high power, focus on a mineral grain free of cracks and inclusions

2- Flip in the auxiliary condenser and refocus open aperture diaphragm up to its maximum.

3- Cross the polars.

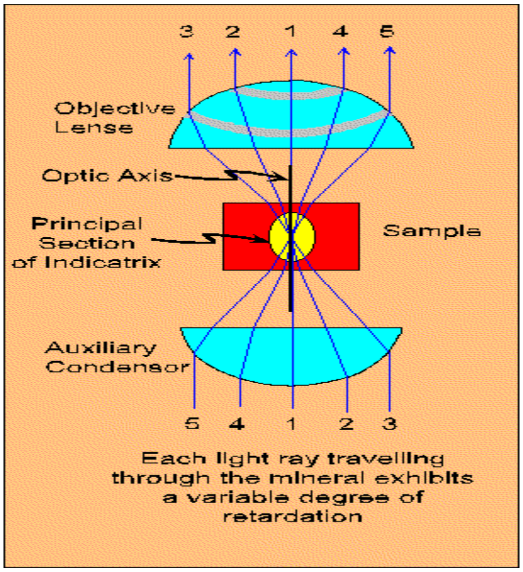
4- Insert the Bertrand lens or remove the ocular.

A cone of light which is focused on the sample, it passes through the sample and is collected by the objective lens.

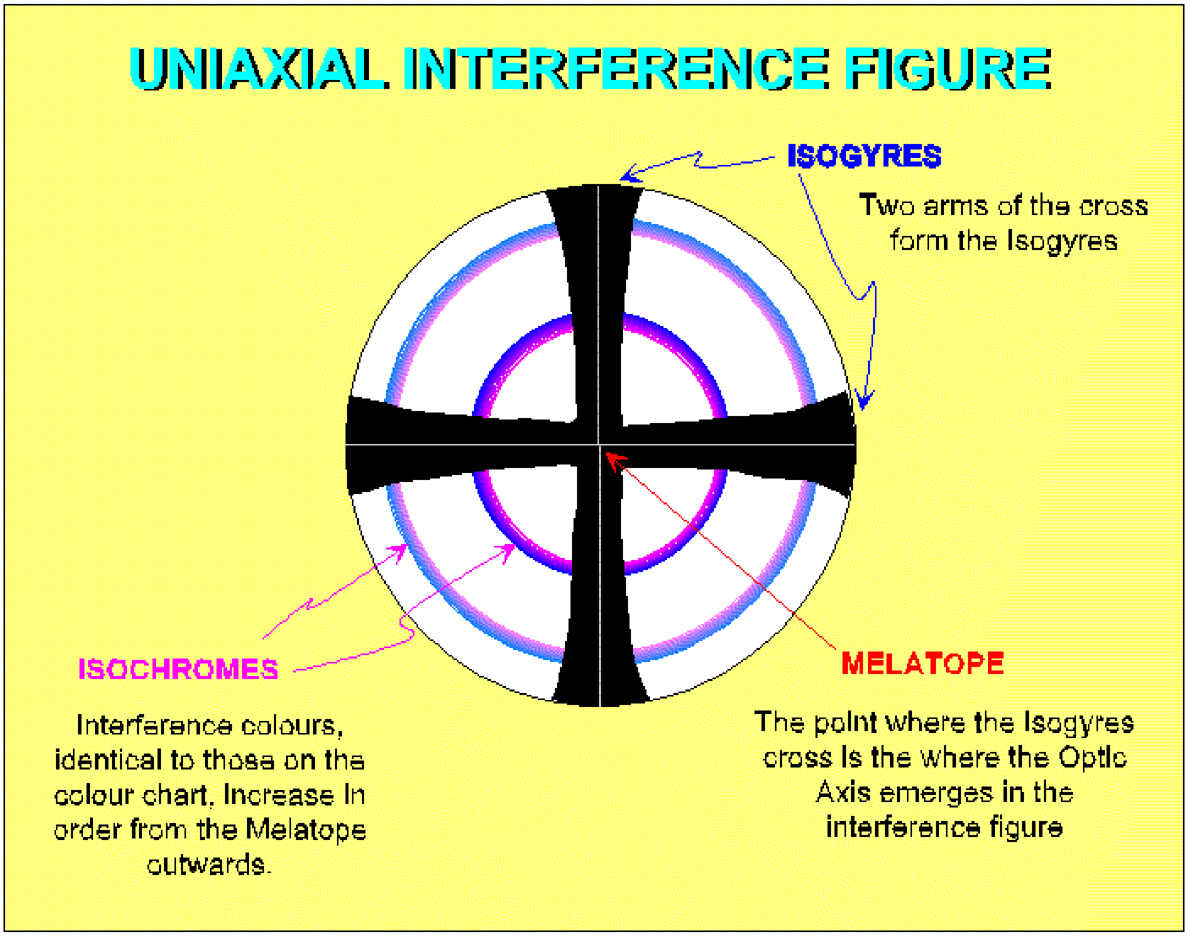
Light which travels along the optic axis does not split into two rays, n epsilon = n omega, and exits the mineral to form the melatope. No retardation "between" rays.

Light following paths 2 & 4 experience moderate retardation n epsilon < n omega ~ 550 nm

Light following paths 3 & 5 experience moderate retardation n epsilon << n omega ~ 1100 nm because light makes a larger angle with optic axis and must take a longer path through the sample.



In uniaxial minerals we will get a centered black cross superimposed on circular bands of interference colours as follows:



The cross consists of two black bands called isogyres whose point of intersection is called melatope and marks the point where the optic axis passes.

Interference colours increase in order outward from the melatope, near melatope colours are low first order. Each colour band is called an isochrome.

Isochromes are formed due to varying retardation of convergent light rays on the sample.

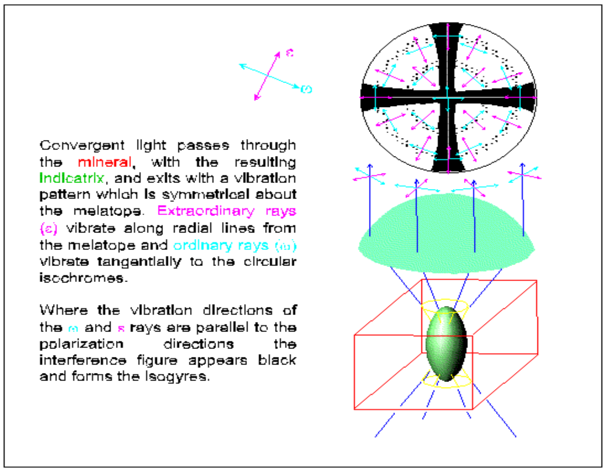
Interpretation:

When the oblique conical rays inter the mineral slice, each of them (but that coincides with the optic axis) splits into two perpendicular rays $n\varepsilon$ (n_e or n_γ) and $n\omega$ (n_o or n_α):

One vibrates tangential (parallel) to the circular isochromes, and perpendicular to the optic.
(These rays are analogous to latitudes on the indicatrixsurface).

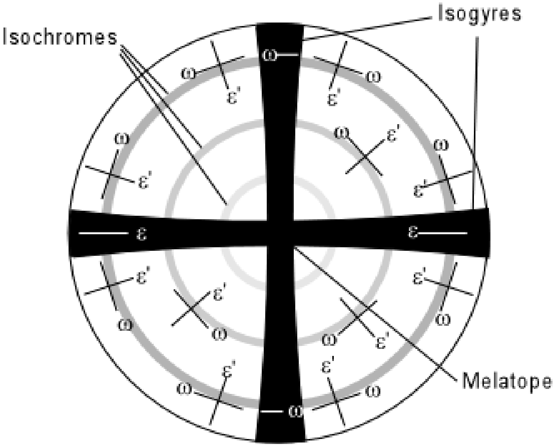
The other vibrates along radial lines from the melatope outwards. parallel to the optic axis (radially from a center)
(These rays are analogous longitudes on the indicatrix surface).

So, isogyres form when the vibration directions of these two rays parallel the vibration directions of the polars, where each polar eliminates one of them leading to extinction.



Convergent light passes through the mineral, with the resulting Indicatrix, and exits with a vibration pattern which is symmetrical about the melatope. Extraordinary rays (ε) vibrate along radial lines from the melatope and ordinary rays (ω) vibrate tangentially to the circular isochromes.

Where the vibration directions of the ω and ε rays are parallel to the polarization directions the interference figure appears black and forms the Isogyres.

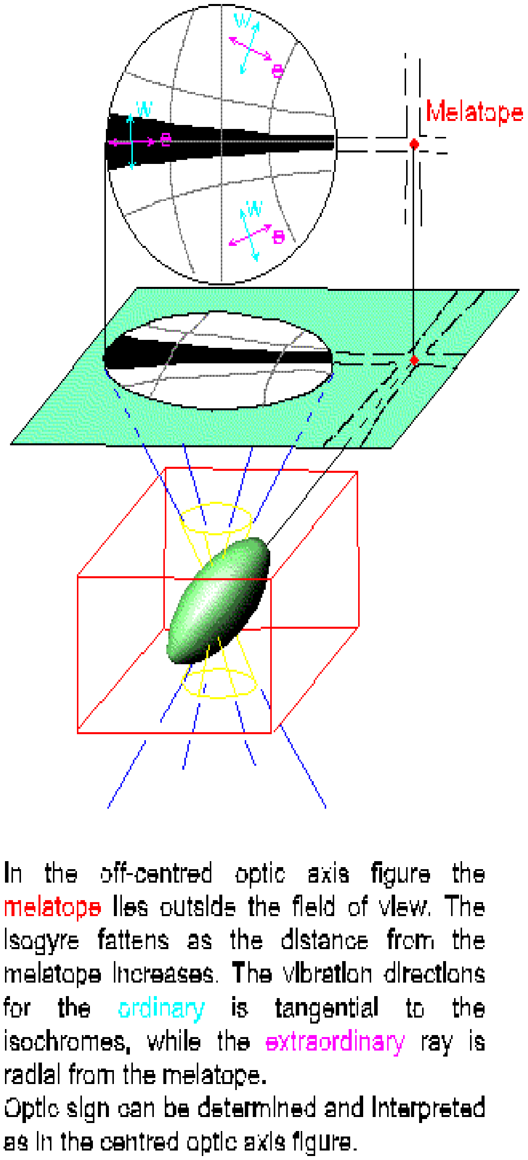


Interference colours appear as circular bands because the optical properties vary symmetrically about the vertical optic axis,

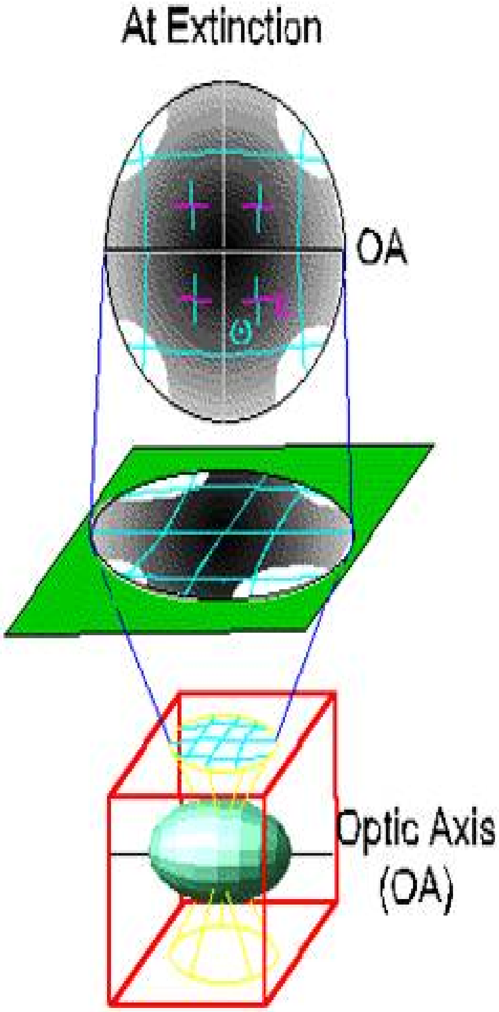
rings of equal retardation are produced around the melatope = isochromes.
Interference colours increase in order outward from the melatope, because birefringence depends on thickness with increases for the tilted ray outwards.

If the section is oblique to the optic axis, the cross will be out of view and we have to rotate the stage. By rotating the stage, we will observe one vertical “arm” of the cross, moving horizontally as we rotate the stage, and when it disappears, a horizontal arm will show up, moving vertically.

In sections parallel to the optic axis we will get flash figure (a very broad, fuzzy isogyres cross).



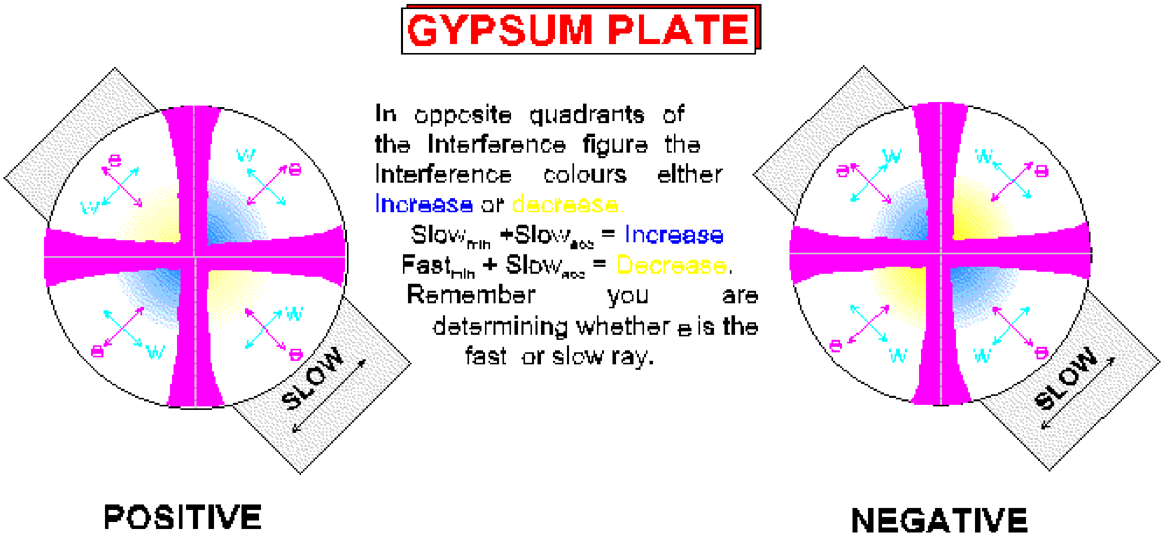
In the off-centred optic axis figure the melatope lies outside the field of view. The isogyre fattens as the distance from the melatope increases. The vibration directions for the ordinary is tangential to the isochromes, while the extraordinary ray is radial from the melatope.
Optic sign can be determined and interpreted as in the centred optic axis figure.



section is oblique to the optic axis

section parallel to the optic axis

(+)ve/(-)ve??



GYPSUM PLATE

In opposite quadrants of the Interference figure the Interference colours either Increase or decrease.

$\text{Slow}_{\text{min}} + \text{Slow}_{\text{acc}}$ = Increase

$\text{Fast}_{\text{min}} + \text{Slow}_{\text{acc}}$ = Decrease.

Remember you are determining whether e is the fast or slow ray.

Blue in the NE and SW

→ colour increased

$n_\varepsilon(n_\gamma)$ gypsum (slow) ≡ n_ε (n_e or n_γ)mineral mineral(fast)

vibrates radially parallel to the optic axis

∴ positive

red/yellow in the NE and SW

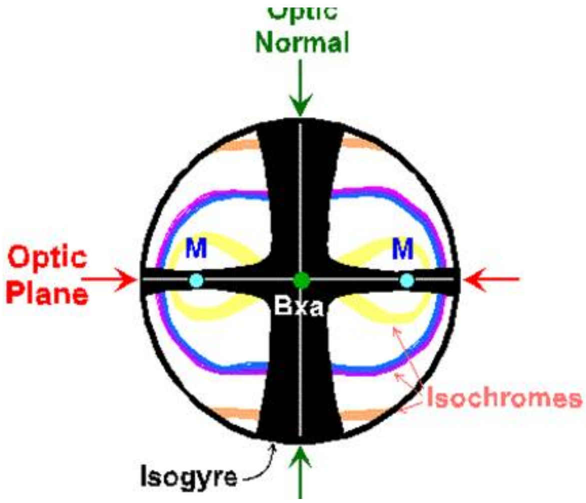
→ colour decreased

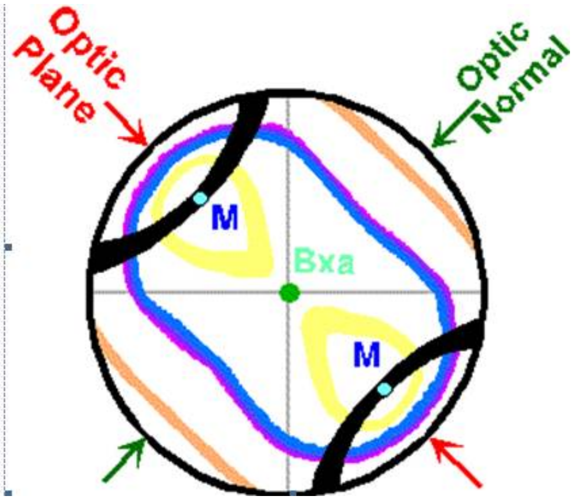
$n_\varepsilon(n_\gamma)$gypsum(slow)≡$n_\omega(n_\alpha)$

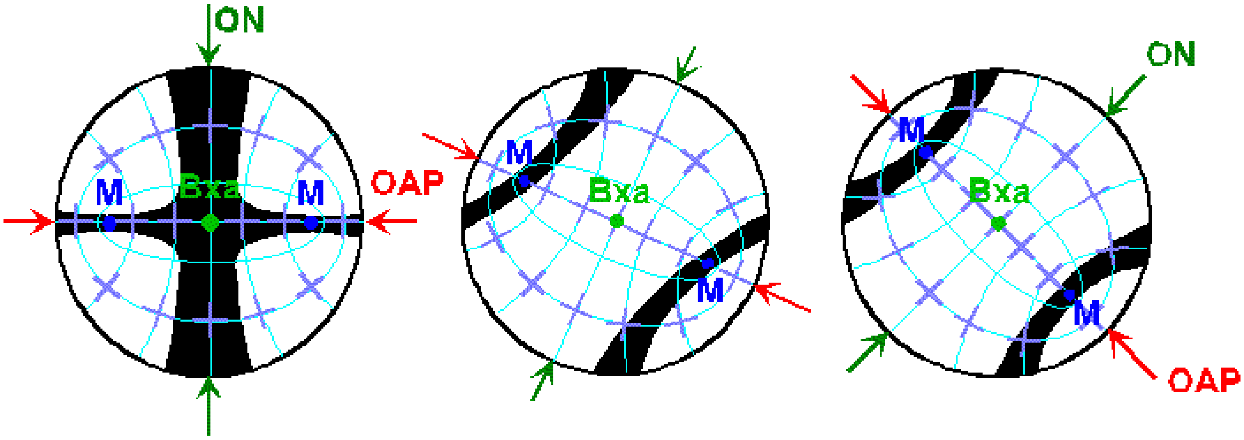
vibrates tangentially (⊥ optic axis)

∴ negative

Biaxial interference Figure

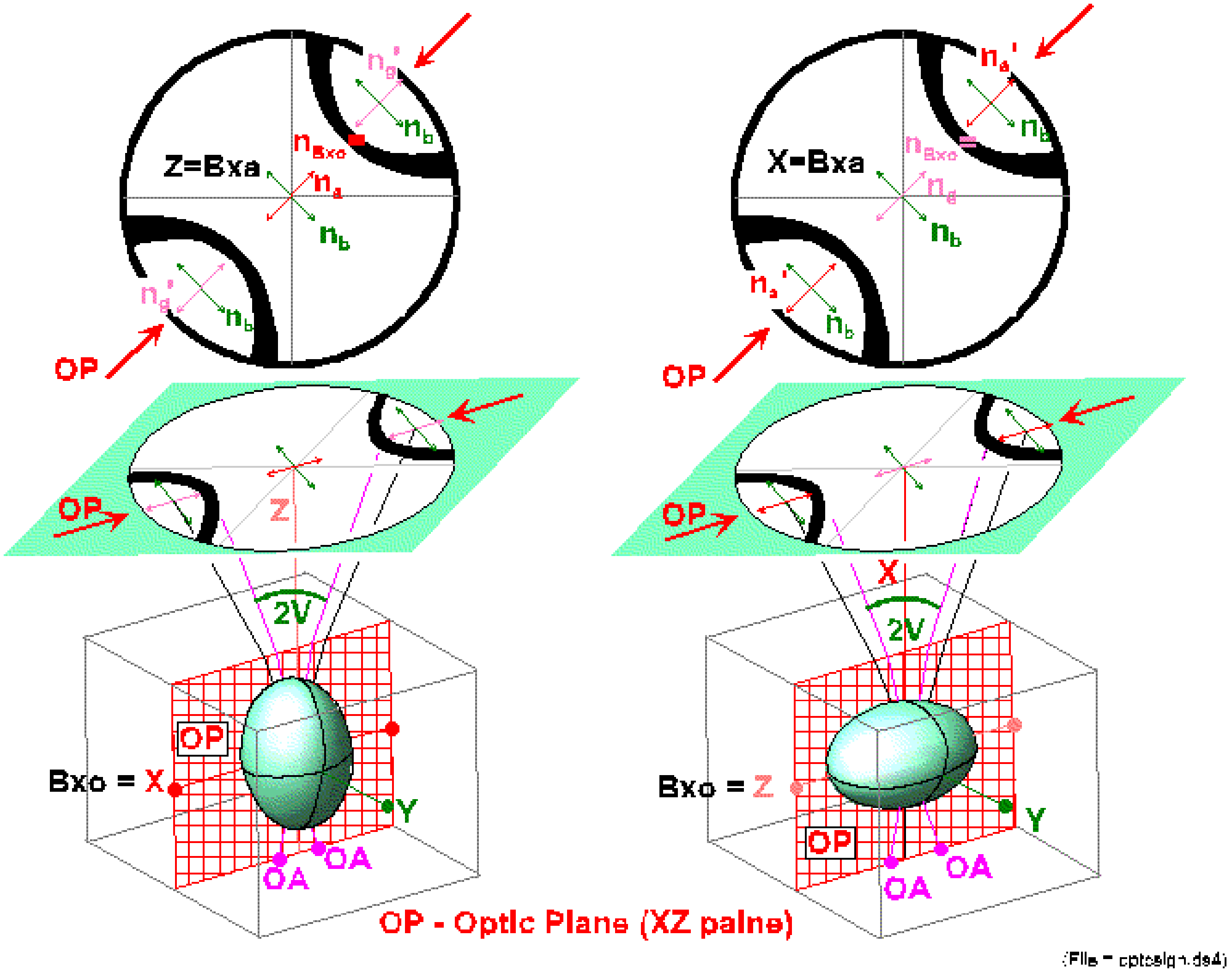


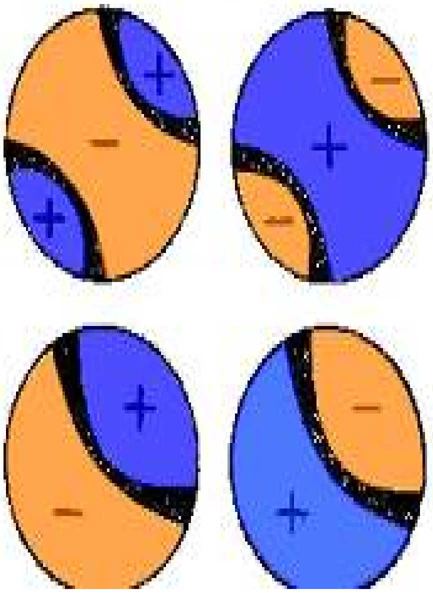




At extinction, left image above, the isogyres will form a cross with arms parallel with the crosshairs.

On rotating the stage to the 45° position, right image above, the cross will split and the isogyres will form two hyperbole which will lie in opposite quadrants of the field of view. The melatopes and/or isogyres will always leave the field of view along the optic axial plane when the stage is rotated and the figure breaks up.





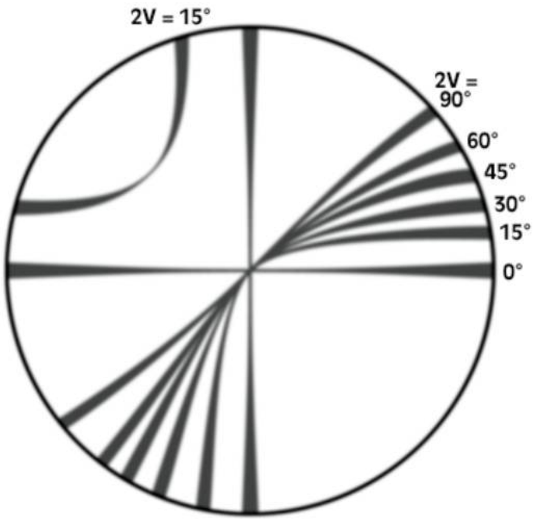
b) Biaxial ⊥ to acute bisectrix

c) Biaxial ⊥ to optic axis

Estimation of the 2V angle:

This estimation is an approximation using the interference figures. The best sections are those perpendicular to the acute bisectrix (Fig. 47a). The estimate is done by comparison withimages from Fig. 47.

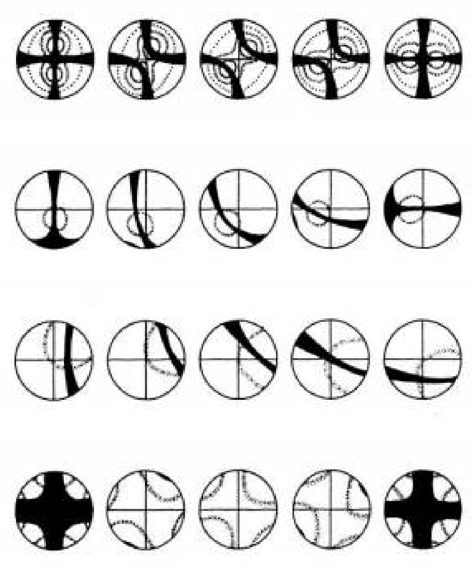
a) 2V=90: one straight line rotating in the opposite direction compared to the rotation of the stage;



The curvature of isogyres in figures centered on an optic axis.can be used to estimate 2V When 2V = 0, as is the case for a uniaxial mineral, the isogyres are orthogonal and correspond to the crosshairs. Isogyres that arise from values of 2V varying from 0–90° are shown here. Lower values of 2V are more curved than higher values.

b) There is a moderate 2V angle if the isogyres are moderately curved;

c) There is a low 2V angle if the two wings of the cross meet and break slightly as we rotate the stage. The two wings do not leave the interference figure when rotating the stage only if the section is ~ perpendicular to the acute bisectrix (i.e. a uniaxial-like interference figure).



The Good: Section ⊥ to the acute bisectrix

The Bad: Section oblique to the acute bisectrix

Another Good one: Section ±⊥ to OA

The Ugly: "Flash Figure"
Section ⊥ to the obtuse bisectrix (biaxial minerals) or parallel to the OA (uniaxial minerals): confusion guaranteed.

حافظوا على الميكروسكوب.....

فهو الوسيلة المتاحة لنا لتعلم هذه الدروس و غيرها، و هو جزء من ثروة الوطن و مقدرات البلاد، لذا فإن حُبَّنا للوطن و انتمائنا له و أيضاً حُبَّنا للعلم و تطلعنا للتعلم ليدفعانا جميعاً أن نحافظَ ليس على الميكروسكوب و فقط بل و على كل الأدوات المتاحة بالكلية بكل حرص و عناية ليتعلمَ به من بعدَنا من شباب الوطن كما تعلم من قبلنا و نتعلم نحن به الآن،

و تحيا مصر.

د. أحمد عبد الرشيد الشيخ