

# Crystallography

## Unit V

### UNIT-V: SYLLABUS

Anisotropism and anisotropic minerals. Behaviour of ordinary light in uniaxial minerals: Double refraction -Indicatrix -Optic axes – Optic sign. Nicol prism and its construction. Behaviour of polarized light in uniaxial minerals. Pleochroism, retardation, birefringence, extinction, and interference colours in uniaxial minerals. Study of Uniaxial minerals using the petrological microscope: under parallel (PN) and crossed Nicol (XN) conditions. Uniaxial interference figure. Behaviour of ordinary light in biaxial minerals. Behaviour of polarized light in biaxial minerals. Study of Biaxial minerals using the petrological microscope: under PN and XN conditions. Biaxial Indicatrix -optic axes and optical axial angles – biaxial extinction and extinction angles –Trichroism. Biaxial interference figure. Michel Levi interference colour chart and orders of interference colour.

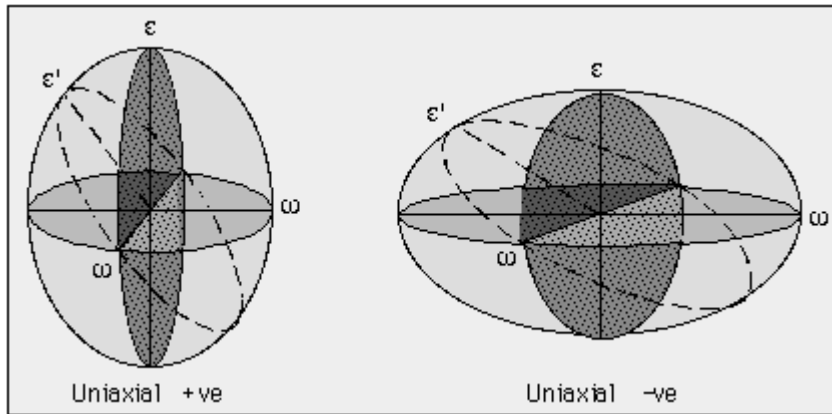
#### Anisotropic and isotropic minerals

Isotropic minerals have the same chemical bonding in every direction, and consequently have the same refractive index in every direction. Light travels through them with a single velocity regardless of the direction of propagation and vibrates in all directions at right angles to the direction of propagation. Isotropic minerals belong to the isometric system.

All minerals that do not belong to the isometric system are anisotropic. Anisotropic minerals have different chemical bonds in different directions and consequently have different refractive indices in different directions. Light that is incident on anisotropic minerals breaks into two polarized rays that vibrate in mutually perpendicular planes and travel with different velocities, according to the refractive indices associated with the direction of propagation. Anisotropic minerals will be discussed later in more detail.

The fact that an isotropic mineral has a single refractive index is very useful. Because it does not change the polarization of incident light, it will appear black when the analyzer is inserted unlike anisotropic minerals.

Behaviour of ordinary light in uniaxial minerals. When light enters a uniaxial mineral it is broken into two rays, the O and E rays. The ordinary ray, or the  $\omega$  ray, vibrates in the basal plane of the mineral, perpendicular to the major axis of the crystal, the optic axis. The "extraordinary" ray, or the  $\epsilon$  ray, vibrates in the plane that includes the optic axis.



## Double refraction

**Double refraction**, also called **birefringence**, an optical property in which a single ray of unpolarized light entering an anisotropic medium is split into two rays, each traveling in a different direction. One ray (called the extraordinary ray) is bent, or refracted, at an angle as it travels through the medium; the other ray (called the ordinary ray) passes through the medium unchanged.

Double refraction can be observed by comparing two materials, glass and calcite. If a pencil mark is drawn upon a sheet of paper and then covered with a piece of glass, only one image will be seen; but if the same paper is covered with a piece of calcite, and the crystal is oriented in a specific direction, then two marks will become visible.

The Figure shows the phenomenon of double refraction through a calcite crystal. An incident ray is seen to split into the ordinary ray  $CO$  and the extraordinary ray  $CE$  upon entering the crystal face at  $C$ . If the incident ray enters the crystal along the direction of its optic axis, however, the light ray will not become divided.

In double refraction, the ordinary ray and the extraordinary ray are polarized in planes vibrating at right angles to each other. Furthermore, the refractive index (a number that determines the angle of bending specific for each medium) of the ordinary ray is observed to be constant in all directions; the refractive index of the extraordinary ray varies according to the direction taken because it has components that are both parallel and perpendicular to the crystal's optic axis. Because the speed of light waves in a medium is equal to

their speed in a vacuum divided by the index of refraction for that wavelength, an extraordinary ray can move either faster or slower than an ordinary ray.

### Indicatrix

As the refractive index varies with the direction of vibration of the light waves for most crystals, it is of great assistance to visualise the values of "n" for all the directions of vibration and relate them to the directions of propagation, which will be perpendicular. The geometric figure which results is called the optic indicatrix.

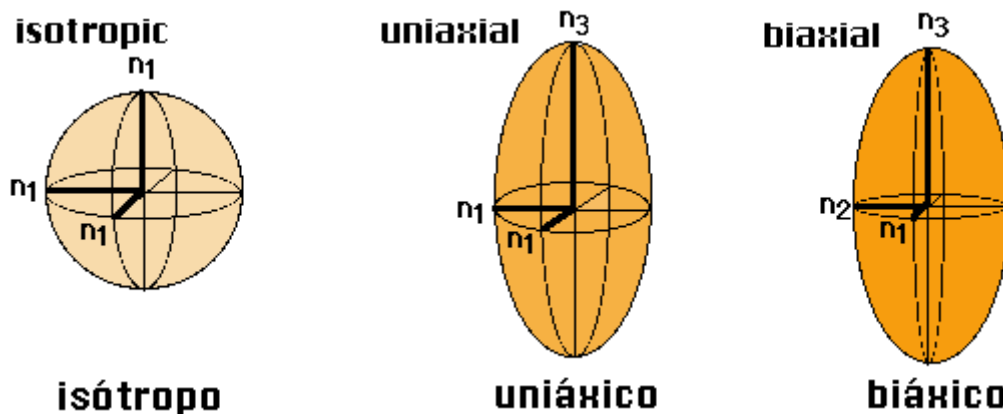
The indicatrices are the representation of the values for "n" for all the directions of vibration of a crystal.

By thus representing the minerals, three types of geometric shapes appear:

-For some minerals, the optic indicatrix is a sphere. This is the case of those that are isotropic.

- For others, it is an ellipsoid of revolution (with two principle axes), which are known as uniaxial anisotropic minerals.

- Finally, another group has an indicatrix which is an ellipsoid with three principle axes, and these are called biaxial anisotropic minerals.



**indicatrix (optical indicatrix, index ellipsoid)** An ellipsoid which represents geometrically the different vibration directions in a mineral and illustrates conceptually the optical features of a crystal. The origin is a point lying at the centre of the ellipsoid and the axes of the ellipsoid are proportional in length to the refractive indices of beams of light vibrating at right angles along them.

These axes are commonly termed X, Y, and Z, or  $n_\alpha$ ,  $n_\beta$ , and  $n_\gamma$ ,

for orthorhombic, monoclinic, or triclinic minerals. Tetragonal, hexagonal,

and trigonal minerals are represented by an indicatrix with one principal section

circular; and the cubic minerals are represented by an indicatrix (the isotropic indicatrix) which is a sphere with all axes equal. Measurements of the elliptical plane sections give optical properties which aid specific identification of a mineral. See OPTIC AXIS.

### Optic axis

An **optic axis of a crystal** is a direction in which a ray of transmitted light suffers no birefringence (double refraction). An optical axis is a direction rather than a single line: all rays that are parallel to that direction exhibit the same lack of birefringence.<sup>[1]</sup>

Crystals may have a single optic axis, in which case they are *uniaxial*, or two different optic axes, in which case they are *biaxial*. Non-crystalline materials generally have no birefringence and thus, no optic axis. A uniaxial crystal (e.g. calcite, quartz) is isotropic within the plane orthogonal to the optic axis of the crystal.

The internal structure of crystals (the specific structure of the crystal lattice, and the specific atoms or molecules of which it is composed) causes the speed of light in the material, and therefore the material's refractive index, to depend on both the light's direction of propagation and its polarization. The dependence on polarization causes birefringence, in which two perpendicular polarizations propagate at different speeds and refract at different angles in the crystal. This causes a ray of light to split into an ordinary ray and an extraordinary ray, with orthogonal polarizations. For light propagating along an optic axis, though, the speed does not depend on the polarization, so there is no birefringence although there can be optical activity (a rotation of the plane of polarization).

The refractive index of the ordinary ray is constant for any direction in the crystal. The refractive index of the extraordinary ray varies depending on its direction.

### Optic sign

Indicates the type of double refraction in a mineral. In uniaxial minerals, the material is said to be positive when the extraordinary ray has a higher refractive index than the ordinary ray and negative when the ordinary ray has the greater index. In biaxial minerals, which have three basic optical directions, the refractive index of the intermediate or beta ray is the criterion; if its refractive index is nearer that of the low or alpha ray, it is said to be a positive mineral or stone; if it is nearer the high or gamma ray, it is said to be a negative mineral or stone.

More technically, in uniaxial minerals, the material is positive when the extreme refractive index ( $n_{\text{epsilon}}$ ) is greater than the apparently isotropic one

( $n_{\omega}$ ) and negative when the extreme refractive index is less. In biaxial minerals, which have extreme refractive indices both above and below the apparently isotropic one ( $n_{\beta}$ ), the material is positive when the lower refractive index ( $n_{\alpha}$ ) is closer to the apparently isotropic one and negative when the higher one ( $n_{\gamma}$ ) is closer.

Synonym of: optical sign, optical character

### Nicol prism and its construction

Nicol prism is an optical device which is used for producing and analyzing plane polarized light in practice.

Principal Nicol Prism is based upon phenomenon of Double refraction.

### Construction

- It is constructed from the calcite crystal PQRS having length three times of its width.
- Its end faces PQ and RS are cut such that the angles in the principal section become  $68^{\circ}$  and  $112^{\circ}$  in place of  $71^{\circ}$  and  $109^{\circ}$
- The crystal is then cut diagonally into two parts. The surfaces of these parts are grinded to make optically flat and then these are polished.
- Thus polished surfaces are connected together with a special cement known as Canada Balsam.

### Working

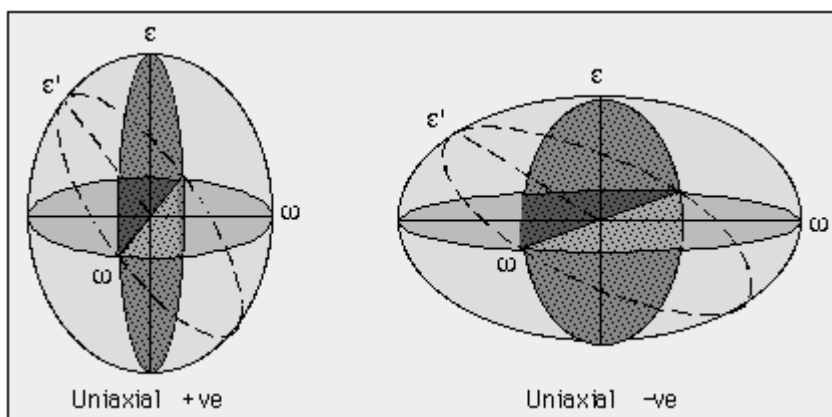
- When a beam of unpolarised light is incident on the face P'Q, it gets split into two refracted rays, named O-ray and E-ray.
- These two rays are plane polarised rays, whose vibrations are at right angles to each other. The refractive index of Canada balsam cement being 1.55 lies between those of ordinary and extraordinary and 1.4864, respectively.
- It is clear from the above discussion that Canada Balsam layer acts as an optically rarer medium for the ordinary ray and it acts as an optically denser medium for the extraordinary ray.
- When ordinary ray of light travels in the calcite crystal and enters the Canada balsam cement layer, it passes from denser to rarer medium. Moreover, the

angle of incidence is greater than the critical angle, the incident ray is totally internally reflected from the crystal and only extraordinary ray is transmitted through the prism.

- Therefore, fully plane polarised wave is generated with the help of Nicol prism.

### Behaviour of polarized light in uniaxial minerals

When light enters a uniaxial mineral it is broken into two rays, the O and E rays. The ordinary ray, or the  $\omega$  ray, vibrates in the basal plane of the mineral, perpendicular to the major axis of the crystal, the optic axis. The "extraordinary" ray, or the  $\epsilon$  ray, vibrates in the plane that includes the optic axis.



### **Introduction to Uniaxial Minerals**

Uniaxial minerals are a class of anisotropic minerals that include all minerals that crystallize in the tetragonal and hexagonal crystal systems. They are called uniaxial because they have a single optic axis. Light traveling along the direction of this single optic axis exhibits the same properties as isotropic materials in the sense that the polarization direction of the light is not changed by passage through the crystal. Similarly, if the optic axis is oriented perpendicular to the microscope stage with the analyzer inserted, the grain will remain extinct throughout a 360° rotation of the stage. The single optic axis is coincident with the c-crystallographic axis in tetragonal and hexagonal minerals. Thus, light traveling parallel to the c-axis will behave as if it were traveling in an isotropic substance because, looking down the c-axis of tetragonal or hexagonal minerals one sees only equal length a-axes, just like in isometric minerals.

- Like all anisotropic substances, the refractive indices of uniaxial crystals varies between two extreme values. For uniaxial minerals these two extreme values of refractive index are defined as  $n_o$  (or  $N_o$ ) and  $n_e$  (or  $N_e$ ). Values between  $n_o$  and  $n_e$  are referred to as  $n'$ .
- Uniaxial minerals can be further divided into two classes. If  $n_e < n_o$  the mineral is said to have a *negative optic sign* or is *uniaxial negative*. In the opposite case, where  $n_e > n_o$  the mineral is said to have a *positive optic sign* or is *uniaxial positive*.
- The absolute *birefringence* of a uniaxial mineral is defined as  $|n_e - n_o|$  (the absolute value of the difference between the extreme refractive indices).

### Pleochroism

Pleochroism is the ability of a mineral to absorb different wavelengths of transmitted light depending upon its crystallographic orientations.

This is the property which some minerals present by which they appear to be a different colour depending on the direction in which they are observed, i.e. according to the direction of vibration of the waves that cross them.

Why does it appear?

Just as the refractive index changes with direction, the selective absorption of light by some anisotropic minerals also does so, and as this is responsible for colour, this changes with direction.

### **Pleochroism = "many colored"**

Pleochroism or dichroism is the change in color evident as the mineral is rotated under plane-polarized light.

The primary cause of dichroism or pleochroism in minerals is due to adsorption of particular wavelengths of light. This selective adsorption of certain wavelengths of light causes the transmitted light to appear colored. This color is a function of the thickness and the particular chemical and crystallographic nature of the mineral.

path, the phenomena of pleochroism is evident. This is observable in plane-polarized light when the polarizers select the light exiting from the mineral. This color depends on which optical path is viewed.

Pleochroic colors are observed and recorded in the mineral data and are generally diagnostic of the particular mineral.

- Note: Colored minerals may not be pleochroic.
- Note: Isotropic minerals are never pleochroic.

Pleochroism	Crystallography
None (no variation in color)	Isotropic minerals are always dark under crossed polarizers. Anisotropic minerals are not. If no color variation is observed on rotation under plane-polarized light then the mineral is non-pleochroic.
Dichroic (two colors observed)	Dichroic minerals are generally always hexagonal, trigonal, or tetragonal.
Pleochroic (three color observed)	Pleochroic minerals are generally always orthorhombic, monoclinic, or triclinic.

### Retardation

In anisotropic crystals, the two rays of light produced by double refraction travel at different velocities through the crystal. It takes the slow ray longer to traverse the crystal than it takes the fast ray. The fast ray will have passed through the crystal and traveled some distance  $\Delta$  beyond the crystal before the slow ray reaches the surface of the crystal. This distance  $\Delta$  is called the retardation.

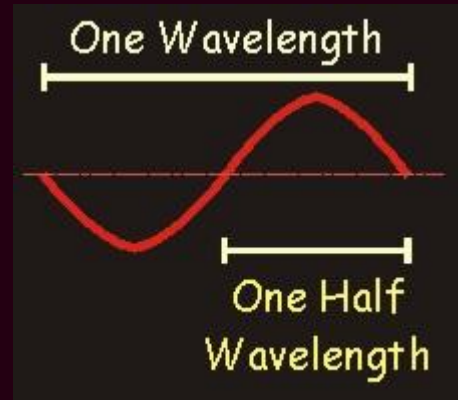
Each of the two light beams travel at a different speed through a mineral sample. The two waves begin traveling from the base of the sample at the same time. However, the faster wave will travel farther than the slower wave in a given amount of time.



The distance that the slow ray lags behind the fast ray by the time that the slow ray finally exits the mineral is called the **RETARDATION**.

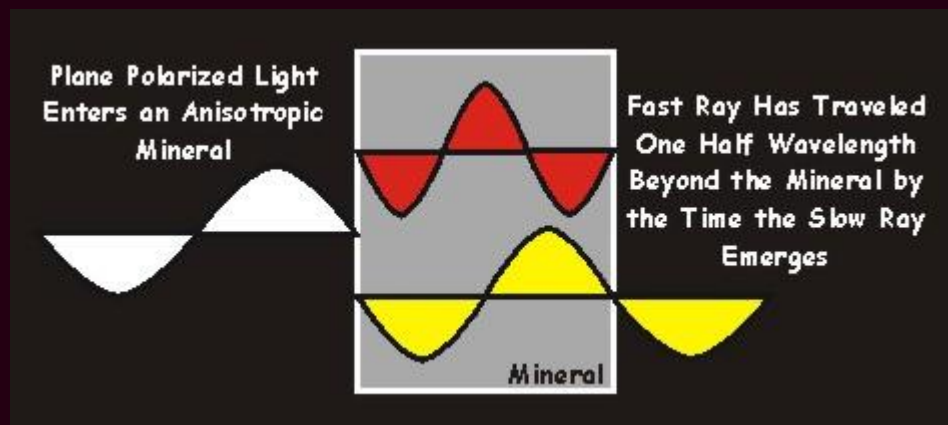
The retardation could be measured in absolute distances. This would most commonly be measured in Angstroms ( $10^{-10}\text{m}$ ) or nanometers (nm) ( $10^{-9}\text{m}$ ).

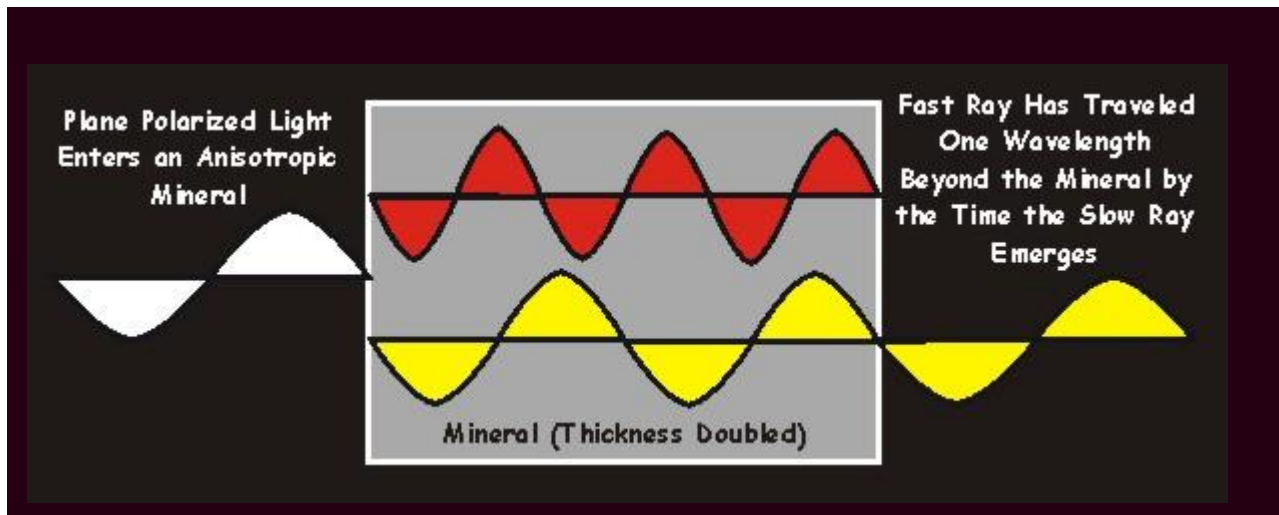
Retardation could also be measured in relative distance compared to the light. How many wavelengths has the light wave lagged behind. Note that a wavelength is the distance over which the wave repeats itself completely.



The greater the difference in velocity, the greater the retardation. Refractive Index is a comparative measure of the speed of light in a medium. Birefringence is a measure of the differential RI. Therefore the greater the **BIREFRINGENCE** of a mineral, the greater the **RETARDATION**.

The further light must travel through an anisotropic grain the more the slow ray will lag behind. Thus the greater the **THICKNESS** of the sample, the greater the **RETARDATION**.





## Birefringence

**Birefringence** is the optical property of a material having a refractive index that depends on the polarization and propagation direction of light.<sup>[1]</sup> These optically anisotropic materials are said to be **birefringent** (or **birefractive**). The birefringence is often quantified as the maximum difference between refractive indices exhibited by the material. Crystals with non-cubic crystal structures are often birefringent, as are plastics under mechanical stress.

Birefringence is responsible for the phenomenon of **double refraction** whereby a ray of light, when incident upon a birefringent material, is split by polarization into two rays taking slightly different paths. This effect was first described by the Danish scientist Rasmus Bartholin in 1669, who observed it<sup>[2]</sup> in calcite, a crystal having one of the strongest birefringences. However, it was not until the 19th century that Augustin-Jean Fresnel described the phenomenon in terms of polarization, understanding light as a wave with field components in transverse polarization (perpendicular to the direction of the wave vector).

## Extinction

**Extinction** is a term used in optical mineralogy and petrology, which describes when cross-polarized light dims, as viewed through a thin section of a mineral in a petrographic microscope. Isotropic minerals, opaque (metallic) minerals, and amorphous materials (glass) do not allow light transmission under cross-polarized light (i.e. constant extinction). Anisotropic minerals specifically will show one extinction for each 90 degrees of stage rotation.

The extinction angle is the measure between the cleavage direction or habit of a mineral and the extinction. To find this, simply line up the cleavage lines/long direction with one of the crosshairs in the microscope, and turn the mineral until the extinction occurs. The number of degrees the stage was rotated is the extinction angle, between 0-89 degrees. 90 degrees would be considered zero

degrees, and is known as parallel extinction. Inclined extinction is a measured angle between 1-89 degrees. Minerals with two cleavages can have two extinction angles, with symmetrical extinction occurring when minerals have multiple angles that are the same. Minerals that have no cleavage or elongation can not have an extinction angle.

Minerals with undulose extinction, solid solution/zonation, or other factors (e.g. bird's eye extinction in mica) that may inhibit this measure and may be more difficult to use.

### Interference colour

In optical mineralogy an **interference colour chart**, first developed by Auguste Michel-Lévy, is a tool to identify minerals in thin section using a petrographic microscope. With a known thickness of the thin section, minerals have specific and predictable colours in cross-polarized light, and this chart can help identify minerals. The colours are produced by the difference in speed in the fast and slow rays, also known as birefringence.

When using the chart, it is important to remember these tips:

- Isotropic and opaque (metallic) minerals cannot be identified this way.
- The stage of the microscope should be rotated until maximum colour is found, and therefore, the maximum birefringence.
- Each mineral, depending on the orientation, may not exhibit the maximum birefringence. It is important to sample a number of similar minerals in order to get the best value of birefringence.
- Uniaxial minerals can look isotropic (always extinct) if the mineral is cut perpendicular to the optic axis (this situation can be revealed with the conoscopic interference pattern).

### Study of uniaxial mineral using the petrological microscope

## **Introduction to Uniaxial Minerals**

### **Under parallel (PN)**

Uniaxial minerals are a class of anisotropic minerals that include all minerals that crystallize in the tetragonal and hexagonal crystal systems. They are called uniaxial because they have a single optic axis. Light traveling along the direction of this single optic axis exhibits the same properties as isotropic materials in the sense that the polarization direction of the light is not changed by passage through the crystal. Similarly, if the optic axis is oriented

perpendicular to the microscope stage with the analyzer inserted, the grain will remain extinct throughout a 360° rotation of the stage. The single optic axis is coincident with the c-crystallographic axis in tetragonal and hexagonal minerals. Thus, light traveling parallel to the c-axis will behave as if it were traveling in an isotropic substance because, looking down the c-axis of tetragonal or hexagonal minerals one sees only equal length a-axes, just like in isometric minerals.

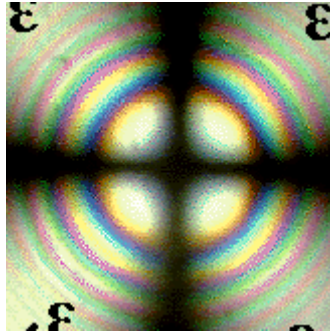
- Like all anisotropic substances, the refractive indices of uniaxial crystals varies between two extreme values. For uniaxial minerals these two extreme values of refractive index are defined as  $n_o$  (or  $N_o$ ) and  $n_e$  (or  $N_e$ ). Values between  $n_o$  and  $n_e$  are referred to as  $n'$ .
- Uniaxial minerals can be further divided into two classes. If  $n_e < n_o$  the mineral is said have a **negative optic sign** or is **uniaxial negative**. In the opposite case, where  $n_e > n_o$  the mineral is said to have a **positive optic sign** or is **uniaxial positive**.
- The absolute **birefringence** of a uniaxial minerals is defined as  $|n_e - n_o|$  (the absolute value of the difference between the extreme refractive indices).
- **Transparent** minerals transmit light, whereas **opaque** minerals block light from passing through them. Because most student microscopes only have an option to look at minerals under transmitted light, this means that **all opaque minerals will appear dark in plane polarized light**. Some very small opaque minerals, or minerals within a group that contains both opaque and transparent minerals (such as the spinel group) may let some light through and could appear to have some color.
- Microscopes with the ability to view thin sections under both reflected and transmitted light do exist, and different opaque minerals will reflect light differently. This type of microscope is most commonly used for studying ore deposits or other rocks containing many opaque mineral species.

### Under crossed nicol

Along the optic axis of the **mineral**, which **in** all instances coincides with the vertical crystallographic axis (c axis), both rays travel with the same speed; **under crossed nicols**, therefore, sections cut normal to the c axis (basal sections) appear isotropic.

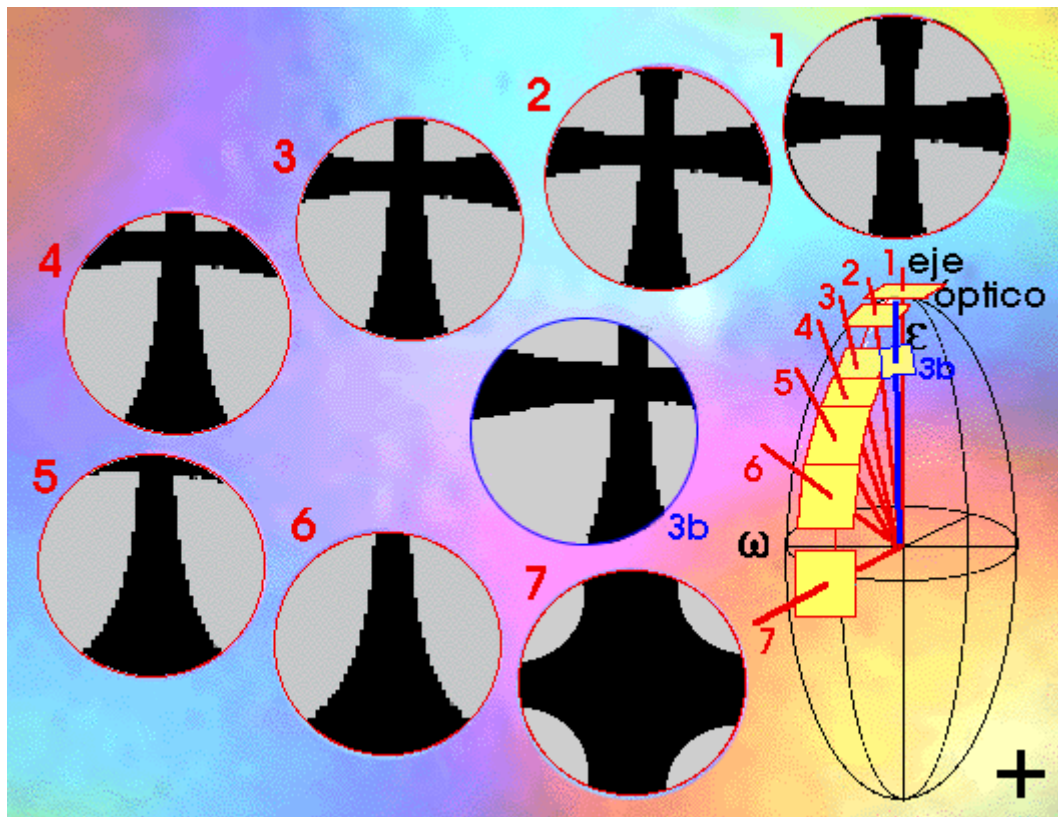
### Uniaxial Interference figures

In uniaxial crystals, the interference figure is formed by an isogyre constituted by two black bands which intersect at right angles, forming a cross, and by various isochromatic curves represented by concentric circles with interference colours which are increasingly higher as they get towards the periphery of the field.

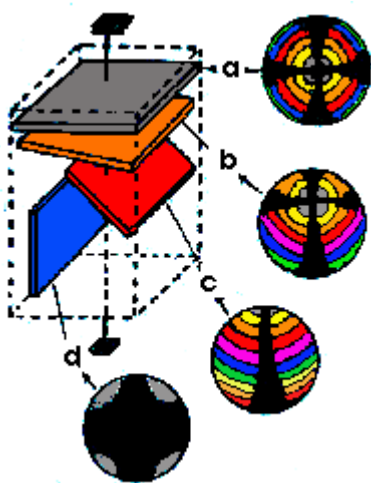


In order to find out whether a certain point in the figure belongs to the isogyre (extinction position) or to an isochromatic curve (general position) you only have to join the point in question to the centre of the cross; the extraordinary component (epsilon) will vibrate in the radial direction and the ordinary component (omega) will vibrate perpendicularly (tangent to the circle). If these coincide with the directions NS and EW, it means that they belong to the isogyre, as they coincide with the directions of vibration of the polariser and analyser. If they do not coincide, they must belong to an isochromatic curve.

The interference figures of uniaxial crystals vary according to the cut of the mineral plate.



### Principal orientations of the cut of the mineral plates



a = cut perpendicular to the optic axis

b = cut inclined to the optic axis

c = cut very inclined to the optic axis

d = cut parallel to the plane of the optic axis

#### a. Cut perpendicular to the optic axis

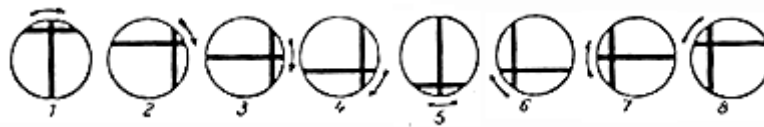
The interference figure is formed by an isogyre constituted by two black bands which intersect at right angles, forming a cross, and by various isochromatic curves represented by concentric circles with interference colours which are increasingly higher as they get towards the periphery of the field. The centre of the isogyre cross coincides with the centre of the microscope field. When turned, no changes occur (it neither moves nor changes shape).

This interference figure identifies it as a uniaxial mineral.

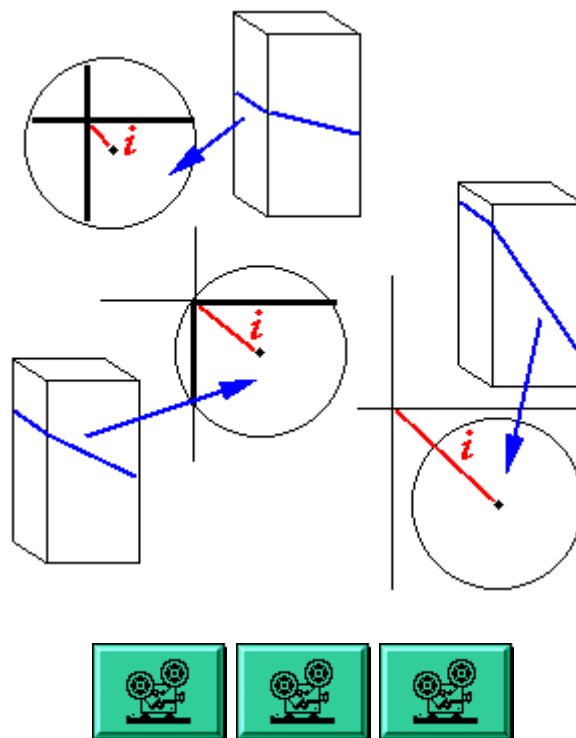
### b. Cut inclined to the optic axis

The interference figure is formed by an isogyre constituted by two black bands which intersect at right angles, forming a cross, and by various isochromatic curves represented by concentric circles with interference colours which are increasingly higher as they get towards the periphery of the field.

The centre of the isogyre cross is displaced from the centre of the field.



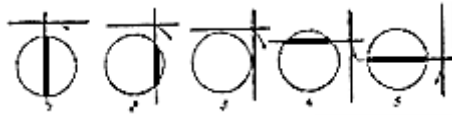
The more inclined the angle, the further the centre of the isogyre cross moves towards the periphery of the field (section "i" in the figure).



This interference figure identifies it as a uniaxial mineral.

### c. Cut very inclined to the optic axis

The interference figure is formed by an isogyre cross whose centre is situated outside the field of view. As it is turned, the figure is seen in parts.



A single isogyre band is seen which moves about the field of view until it disappears altogether. Sometimes it is the vertical band of the isogyre cross that enters the field and sometimes the horizontal one does so.

Theoretically, a crystal can always be identified as uniaxial when the bands remain straight, and do not bend, when leaving the field. In practice, however, there can be some confusion, and it is preferable to look for other grains of the mineral with different cuts.

#### **d. Cut parallel to the plane of the optic axis**

When the cut is parallel to the optic axis (optical axes lie in to the plane of the section), a flash figure is formed, which is characterised by an isogyre cross made up of extraordinarily broad bands which occupy nearly the whole field of view. However, when the microscope stage is turned even slightly ( $<5^\circ$ ), it disappears completely.

#### Behaviour of ordinary light in biaxial minerals

Light interacts with matter in several ways. A ray of light directed at an opaque substance, that is, having metallic luster, is reflected totally (see Ore Microscopy). Light incident upon nonopaque substances-gas, liquid, or solid-is reflected, refracted, and absorbed (see Color in Minerals).

The phenomenon of color in minerals, as in other substances, is due to the absorption of light. When white light is passed through a mineral or reflected from its surface, a certain amount is absorbed and converted to heat energy. If the light is absorbed completely the resulting color is black; if all wavelengths are absorbed equally but not completely, the result is gray; and if absorption is selective, the mineral shows a color that depends on the wavelength(s) transmitted or reflected.

In addition to being a useful aid in identification, the color of minerals may be of commercial importance, as in the case of the ochres and other mineral pigments, and, most notably, the gems and semiprecious stones. Mineral color may be described in terms of hue (the portion of the spectrum represented) and tone (relative brightness); for instance, “*Malachite* is emerald-green to grass-green; *azurite* , light azure to deep blue” (Kraus and Slawson, 1939, p. 207).

The color of a mineral may be due...



**Light** traveling parallel to any one of these directions is resolved into two plane polarized rays, both of which are **ordinary**. For **light** traveling parallel to Y, one ray has the maximum RI ( $n_\gamma$ ) for the **mineral** and the other has the minimum RI ( $n_\alpha$ ). (Alternatively, these are denoted  $n_z$  and  $n_x$ .)

### Behaviour of polarized light in biaxial minerals

All **biaxial minerals** have optical symmetry equivalent to  $2/m2/m2/m$ . ... Just like in **uniaxial minerals**, if one is looking down one of the optic axes, **light** ... with the OAP lying parallel to the **polarizing** direction of the microscope.

All biaxial minerals have optical symmetry equivalent to  $2/m2/m2/m$ . But, in each of the crystal systems, the optical directions have different correspondence to the crystallographic directions.

- In orthorhombic crystals the optical directions correspond to the crystallographic axes, i.e. the X direction and its corresponding refractive index,  $n_x$  can be either the a, b, or c crystallographic axes, the Y direction and  $n_y$  can be parallel to either a, b, or c, and the Z direction or  $n_z$ , can be parallel to either a, b, or c.
- In monoclinic crystals, one of the X ( $n_x$ ), Y ( $n_y$ ), or Z ( $n_z$ ) directions or indices is parallel to the b crystallographic axis, and the other two do not coincide with crystallographic directions.
- In triclinic crystals none of the optical directions or indices coincide with crystallographic directions, although in some rare case one of the indices might coincide with one of the crystallographic directions.

### Biaxial minerals using petrological microscope

- Crystallographic properties of orthorhombic, monoclinic and triclinic minerals are specified with reference to the unit cell, which is measured along three crystallographic axes, a, b and c
- Also necessary to specify three different indices of refraction for biaxial minerals –  $n_\alpha$ ,  $n_\beta$ ,  $n_\gamma$ , where  $n_\alpha < n_\beta < n_\gamma$
- Maximum birefringence therefore is defined as:  $n_\gamma - n_\alpha$  ERSC 2P22 – Brock University Greg Finn CLARIFICATION!

- It takes 3 indices of refraction to describe the optical properties of biaxial minerals, however light entering a biaxial mineral is split into two rays
- The two rays behave as the extraordinary ray did in uniaxial minerals, i.e. both rays are extraordinary and are referred to as the slow and fast rays
- Ordinary and extraordinary terminology is not used when discussing Biaxial Minerals

Orthorhombic, monoclinic, triclinic minerals Two optic axes, hence the name Velocity of light is function of ray path Light entering crystal will be polarized into two of three possible vibration directions mutually perpendicular Vibration directions X, Y, Z Orthorhombic system: XYZ coincide with a, b, c crystallographic axes Monoclinic: One of the vibration directions coincides with b axis Triclinic: no coincidence of XYZ and axes Refractive Ind:  $n\alpha$ ,  $n\beta$ ,  $n\gamma$  with  $n\alpha < n\beta < n\gamma$  Biaxial Indicatrix: triaxial ellipsoid Axes  $\propto n\alpha$ ,  $n\beta$ ,  $n\gamma$  3 Principal sections, 2 circular sections Optic axes lie in XZ plane (optic plane) OA are  $\perp$  circular sections  $2V$  = angle between optic axes (+) Z is Bxa; (-) X is Bxa

Light passing through crystal normal to XZ plane has max difference in RI ( $n\gamma - n\alpha$ ), i.e., max birefringence, and highest interference colors. Light passing through crystal parallel to optic axis behaves as if crystal is isotropic (grain remains dark as stage is rotated). All other orientations show intermediate effects (a) Orthorhombic: X, Y, Z coincide with a, b, c (b) Monoclinic: Y = b. X and Z lie in a-c plane (010) (c) Triclinic: no coincidence except by chance

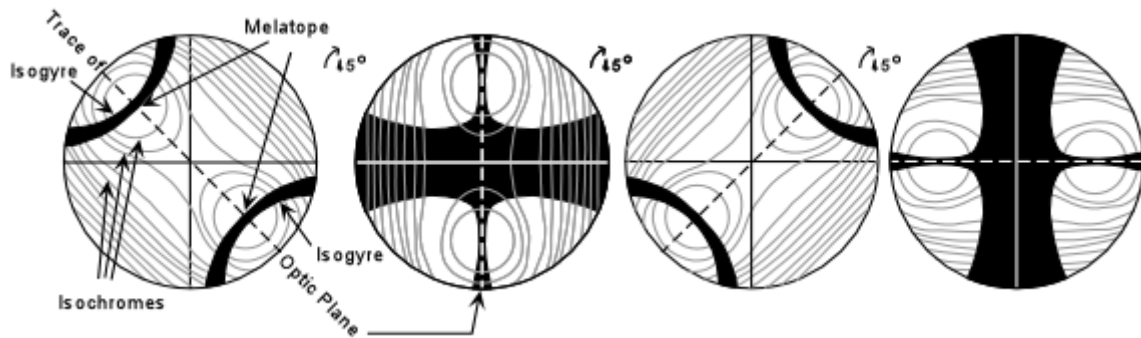
### Biaxial interferences figures

#### **Biaxial Interference Figures**

Four primary types of biaxial interference are seen. Only two of these are commonly used, but it is essential to discuss all four so that you can recognize each.

#### **Acute Bisectrix Figure (BX<sub>A</sub>)**

Looking down the acute bisectrix, (the  $\square$  direction perpendicular to the stage if the crystal is optically positive, or the  $\square$  direction perpendicular to the stage if the crystal is negative), at  $45^\circ$  off extinction in conoscope mode, one would see the interference figure shown in the left-hand diagram below.



- The dark isogyres mark the positions where light vibrating parallel to the polarizer has passed through the crystal.
- At the points of maximum curvature of the isogyres are the two melatopes that mark the positions where rays that traveled along the optic axis emerge from the field of view.
- Note that the distance between the two melatopes is proportional to the angle  $2V$  between the optic axes.
- Also seen are isochromes, which show increasing interference colors in all directions away from the melatopes. The number of isochromes and maximum order of the interference colors seen will increase with increasing thickness and absolute birefringence of the crystal.
- Shown in the figure is the trace of the optic axial plane which includes the two optic axes.

As the stage is rotated  $45^\circ$  from this initial position, the isogyres will close to produce a cross. In this position the crystal would be extinct in orthoscope mode. The melatopes will be rotated so that both lie along the N-S cross hair.

Rotation by an additional  $45^\circ$  will result in the isogyres then separating again to show the interference figure in the third diagram. Another  $45^\circ$  rotation will again cause the isogyres to close into a cross, this time with the OAP lying parallel to the polarizing direction of the microscope. The crystal would again be extinct in orthoscope mode. Another  $45^\circ$  rotation would return the view to the first diagram in the series.

### Petrological microscope

#### Under PN

#### Trichroism

a single optic axis), and trichroism, found in biaxial crystals (two optic axes). It can be observed only in coloured, doubly refracting crystals. When ordinary light is incident on a crystal exhibiting double refraction, the light is split into two polarized components, an ordinary ray and an extraordinary ray, vibrating...

**Pleochroism**, (from Greek *pleiōn*, “more,” and *chrōs*, “colour”), in optics, the selective absorption in crystals of light vibrating in different planes.

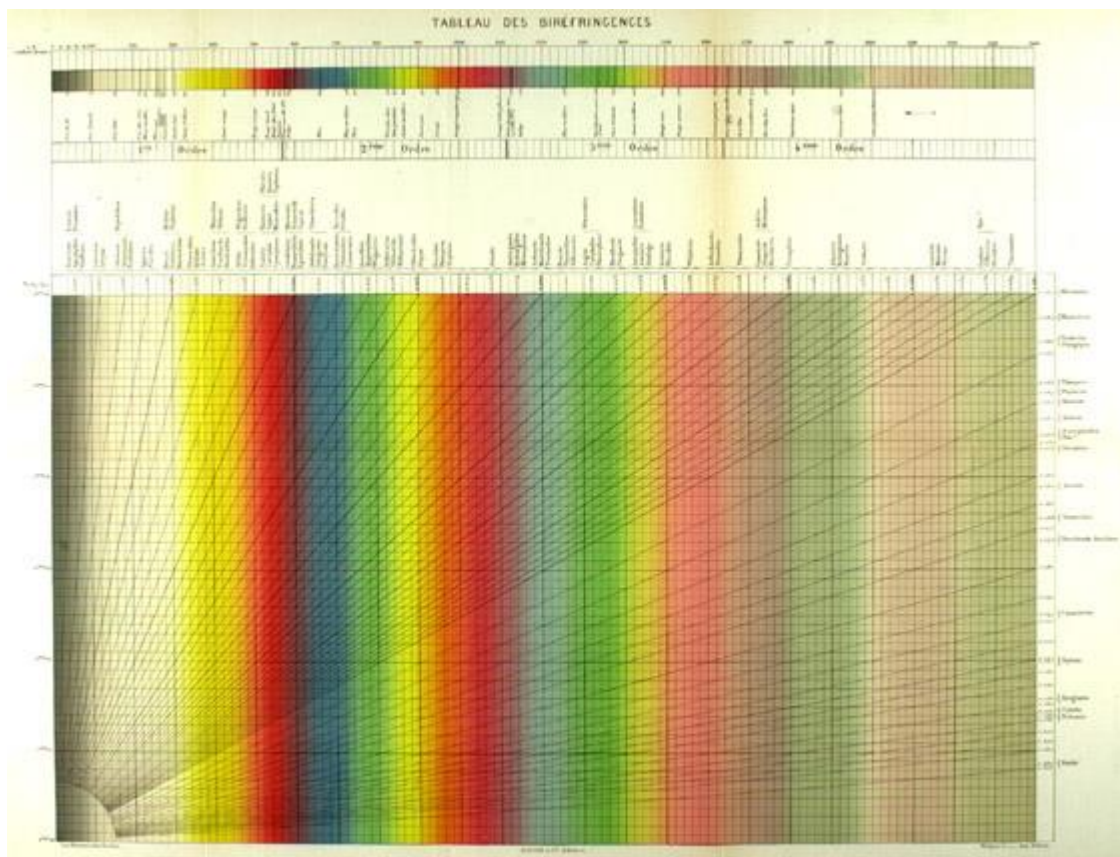
Pleochroism is the general term for both dichroism, which is found in uniaxial crystals (crystals with a single optic axis), and trichroism, found in biaxial crystals (two optic axes). It can be observed only in coloured, doubly refracting crystals. When ordinary light is incident on a crystal exhibiting double refraction, the light is split into two polarized components, an ordinary ray and an extraordinary ray, vibrating in mutually perpendicular planes. A dichroic substance such as tourmaline transmits only the extraordinary ray, having absorbed the ordinary ray (*see* illustration).

When a ray of unpolarized (ordinary) light falls on a dichroic uniaxial crystal, any given wavelength will be absorbed differently according to which plane it is vibrating in, except along the optic axis for which there is no distinction between an ordinary ray and an extraordinary ray. Thus, the dichroic crystal will appear to have one colour in the direction of the optic axis and a different one at other angles. A biaxial crystal, one having two optic axes, will exhibit trichroism, in which three colours, sometimes called face colours, may be observed. As an example, in the crystal cordierite, when white light travels through the crystal parallel to one of the three crystal axes, either violet, blue, or yellow light will be absorbed. If a cube is cut having the crystal axis for edges, the three residual colours will be mixtures of blue plus yellow, violet plus yellow, and violet plus blue.

A pleochroic halo is a spherical shell of colour produced around a radioactive impurity included in a mineral. Such a shell—observed as a ring, or halo, if the specimen is cleaved along a plane passing through the sphere—is believed to represent a region in which the crystal structure has been modified by the absorption of the energy of alpha particles emitted by the radioactive elements. Because most of the energy of an alpha particle is absorbed at the end of its path length in a mineral, these colour centres are produced most intensely around the inclusion. Pleochroic halos are commonly found in rock-forming minerals—for example, biotites, fluorites, and amphiboles. The most common inclusions are the minerals zircon, xenotime, apatite, and monazite.

Michel levi interference colour chart

The Michel-Lévy interference color chart has been in continuous use by analytical microscopists for more than 100 years. Why such endurance? Because this chart, also known as the Michel-Lévy Table of Birefringence, is just as useful today as it was over a century ago in unlocking the many mysteries of microscopic particle analysis and identification. This extraordinarily valuable aid to the polarized-light microscopist graphically relates the thickness, retardation (optical path difference), and birefringence (numerical difference between the principal refractive indices) for particular views of transparent, colorless or colored substances. These characteristics allow unknown materials to be identified; additionally, they provide important optical information about those materials whose identity is known.



The early applications of the Michel-Lévy interference color chart were in the fields of mineralogy and petrology, for the identification of mineral grains in rock thin-sections, and also for comminuted, free mineral grains. The general utility of the chart, however, is such that today it is used as an aid not only for the identification of minerals, but synthetic textile fibers, chemicals, food and food-processing ingredients, biologicals, drugs, catalysts, ores, fertilizers, explosives, etc., etc. In fact, the chart is today used routinely by analytical microscopists in the identification of almost all dust-size particles regardless of nature or origin; it is fundamental to the use of *The Particle Atlas* (2). Some specific fields of application include criminalistics (trace evidence analysis), air

pollution, pharmaceuticals, aerospace, papermaking, microelectronics, fibers, polymers, explosives, manufacturing, graphic arts, and brewing!

What about the “interference color” in the name of the chart? Colors due to the interference effects of light are commonly seen in soap bubbles, oil films or slicks, and between two pieces of glass that are stuck together (separated by a very thin layer of air). These colors are often mistakenly referred to as “rainbow” colors; they are, in fact, not solar spectral colors at all (notice the magentas, grays and white in a thin layer of oil on water next time you see an oil slick). The same kinds of interference colors seen in soap bubbles and oil films are seen in most microscopic particles, when the observation is made with a polarized-light microscope. The polarized-light microscope – the principal investigative instrument for the observation of these interference colors – is, essentially, a conventional microscope with the addition of polarizing elements above and below the specimen, usually in the “crossed” position, i.e., with their “preferred vibration directions” perpendicular to one another. The lower polarizer, or “polar” as it is familiarly referred to by those in the field, is usually oriented in the microscope so that its vibration direction runs “East-West” (left-right; 3 o’clock-9 o’clock); the upper polarizer, called the “analyzer,” is oriented so that its vibration direction runs “North-South” (12 o’clock-6 o’clock). The vibration direction of any polarizer may be determined by viewing reflections from a horizontal, non-metallic surface through the polarizer. All such reflections have their polarization oriented horizontally, i.e., “East-West.” View a reflected highlight on a horizontal shiny non-metallic surface through the polarizer while rotating it. The reflection will be seen to disappear twice on complete rotation of the polarizer; in these positions, the vibration direction of the polarizer is “North-South,” canceling the “East-West” reflection polarization. Try this with a pair of polarizing sunglasses, whose vibration directions are, of course, oriented “North-South” (i.e., up-and-down) to eliminate, or cancel out, the natural “East-West” (left-right) orientation of light reflected from water, glass, and other shiny, non-metallic surfaces.

Any bio-medical type microscope can be converted for interference color observation by placing one polarizing element, the “polarizer,” anywhere below the specimen in the light path, such as over the light exit port, in the filter carrier, between the lenses of the condenser, on the top lens of the condenser, but not too near the light source. Orient the polarizer vibration direction “East-West.” The second polarizing element, the “analyzer,” is placed in a “crossed” position anywhere above the specimen, such as on the back of the objective, in the eyepiece, on the eyepiece diaphragm, or on top of the top (eye) lens of the eyepiece. Orient the analyzer vibration direction “North-South.” But a true polarized-light microscope with graduated, rotating polars; graduated, rotating

stage; slot for accessory plates; Bertrand lens; and other features is necessary for more advanced, quantitative optical crystallography.

Let's look a little more closely at the Zeiss rendition of the Michel-Lévy chart – Figure 4. Notice that the thickness,  $t$ , increases along the ordinate on the left side of the chart from 0  $\mu\text{m}$  to 50  $\mu\text{m}$ , and is numbered at 10  $\mu\text{m}$  intervals. Along the bottom of the chart, left to right, the path difference, or retardation,  $r$ , increases from 0 nm to over 1744 nm, and is marked at specific values of retardation, 0, 40, 97, 158, 200, 218, 234 ..... 1744nm (this chart uses the older designation millimicrons,  $m\mu$ , for nm). The names of the interference colors are also given. First-order red falls at about 550 nm; second-order red at two times 550, or 1,100 nm; third-order red at three times 550, or 1,650 nm, etc. The birefringence ( $n_2-n_1$ ) is plotted along the top and right side of the chart; it starts at zero at the upper-left corner, and proceeds to the right 0.001, 0.002, 0.003, 0.004 ..... to 0.036 at the upper-right corner, and then proceeds downward, graduated differently, 0.040, 0.045, 0.050, 0.055 ..... down to 0.180, and beyond.

Notice the family of diagonal lines originating at the lower left and going out to each value of birefringence. The diagonal lines represent the birefringence values, because  $t = r/B$  is the equation for a straight line through the origin of the coordinates with a slope of  $\tan \theta = 1/B$ . Each line is assigned an angle  $\theta$ , and thereby a special value  $B$ . The names of many substances appear opposite their characteristic maximum birefringence value on many versions of the chart. On this Zeiss chart (Figure 4), minerals are listed by their identifying birefringence. We mentioned quartz earlier; its name is listed at 0.009; spodume is at 0.020; olivine is at 0.036; calcite is near the bottom-right of the chart, near 0.180 – a high birefringence; a large numerical difference between its refractive indices ( $\omega = 1.6584$ ;  $\epsilon = 1.4864$ ;  $1.6584 - 1.4864 = 0.1720$ ).

By

M.P.kowsalya

## References

- <https://sites.und.edu/bireferences>
- <https://www.britannica.com>
- <https://www.tulane.edu>
- <https://edafologia.ugrs.es>
- <https://uasb.academia.edu>