Optical Mineralogy

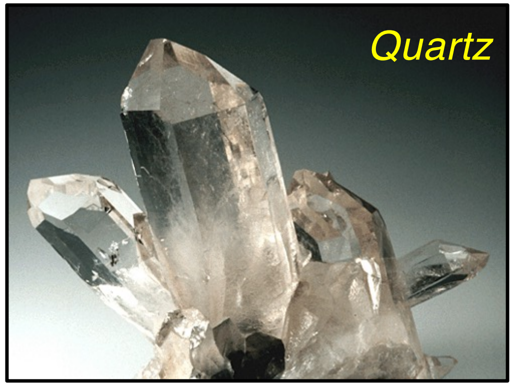
Dr. Tapabrato Sarkar

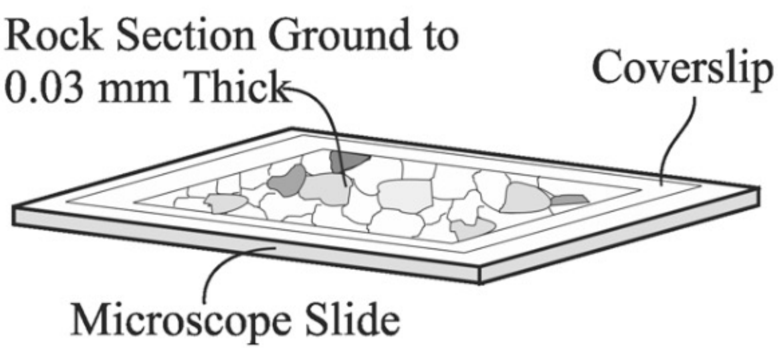
Introduction

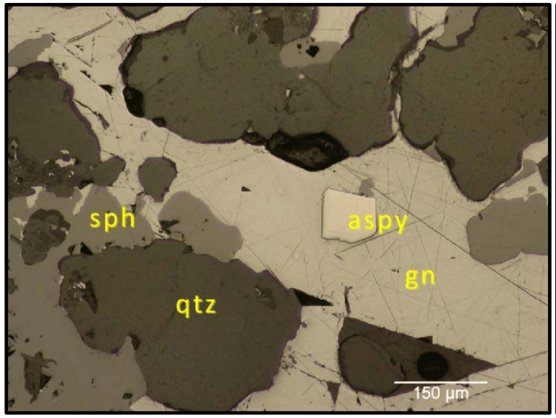
❑ What is optical Mineralogy?

Analysing thin slices of minerals or rocks under transmitted or reflected light.

- **Thin sections** are thin slices of rock or mineral mounted on a microscope slide.
- They are prepared by cementing a piece of rock to a microscope slide and then grinding it to its final thickness, usually **0.03 mm**.







Reflected light

Transmitted light

Petrographic Microscope

A specialized instrument that utilizes polarized light to allow measurement of a variety of properties

These properties are called **optical properties**.

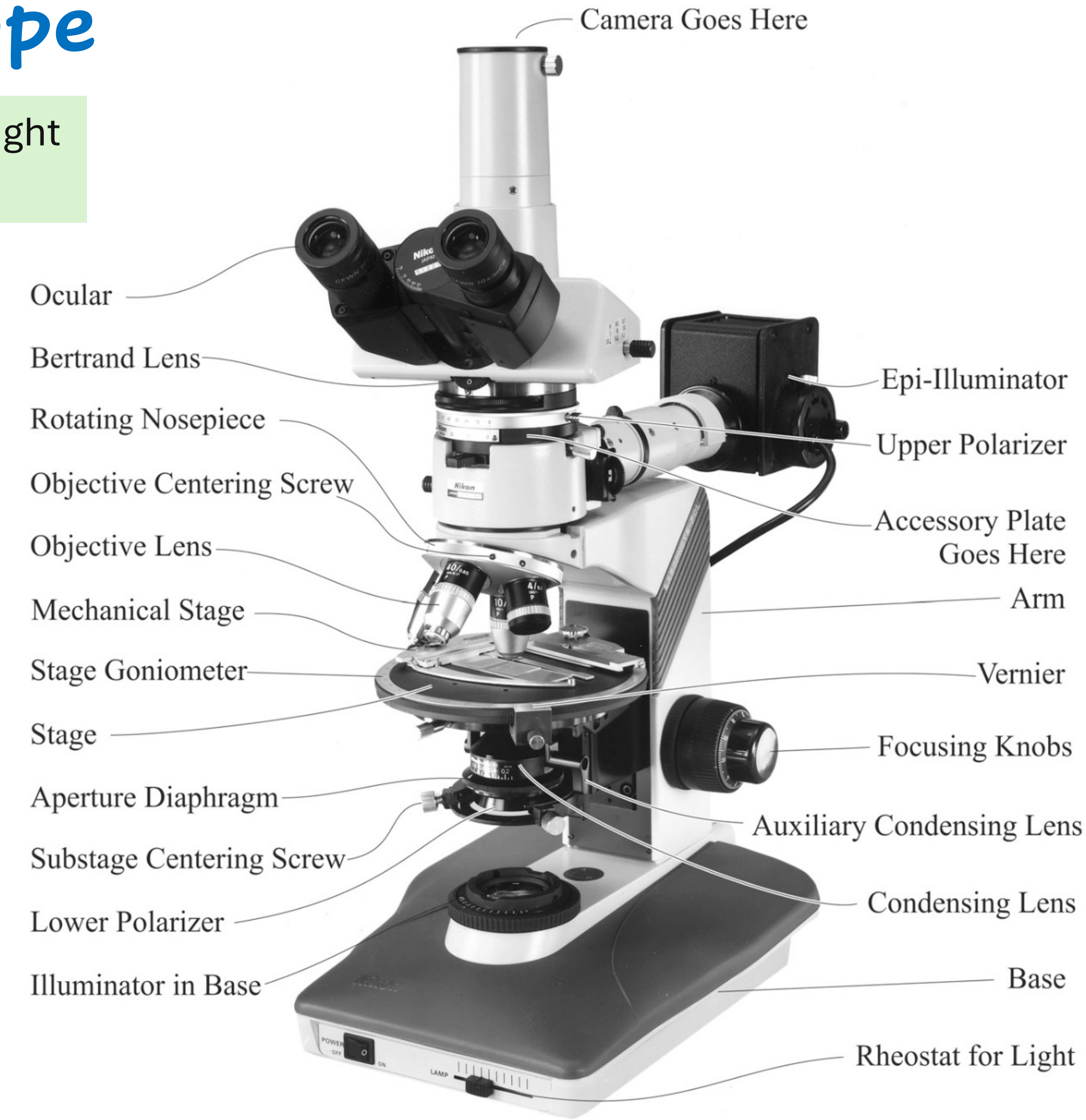
Petrographic microscope provides one of the primary means of studying minerals and the rocks they comprise.

- **Why do we require a microscope?**

✓ Grain size too small to observe the properties in hand specimen

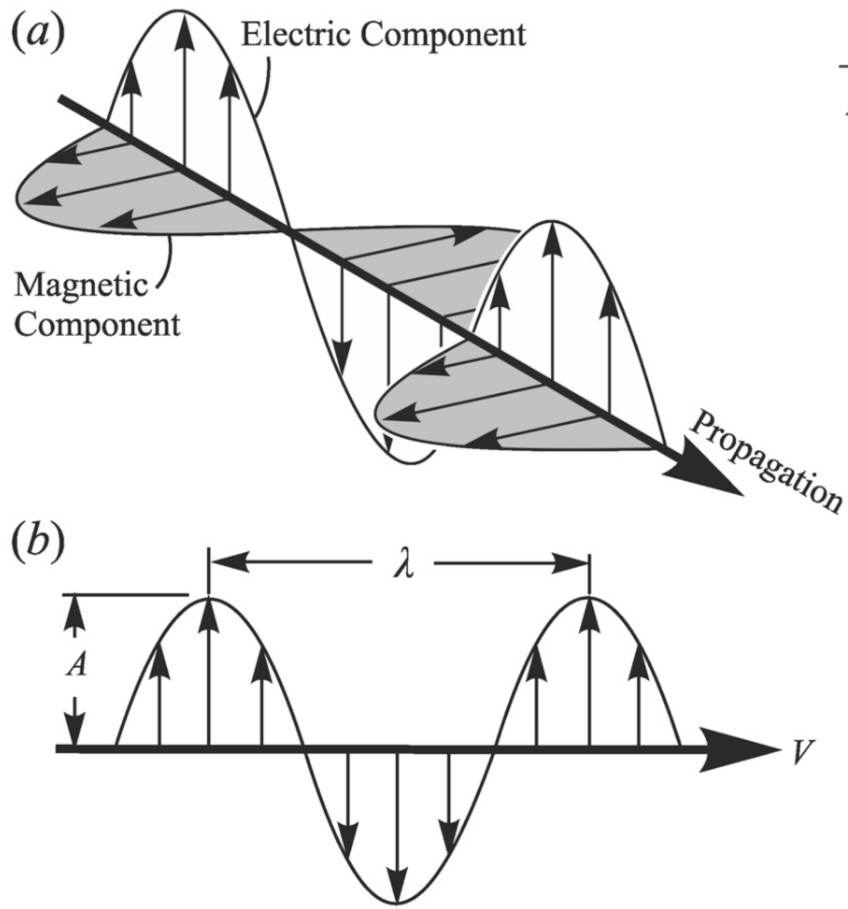
✓ Microscopic properties which cannot be observed in a hand specimen

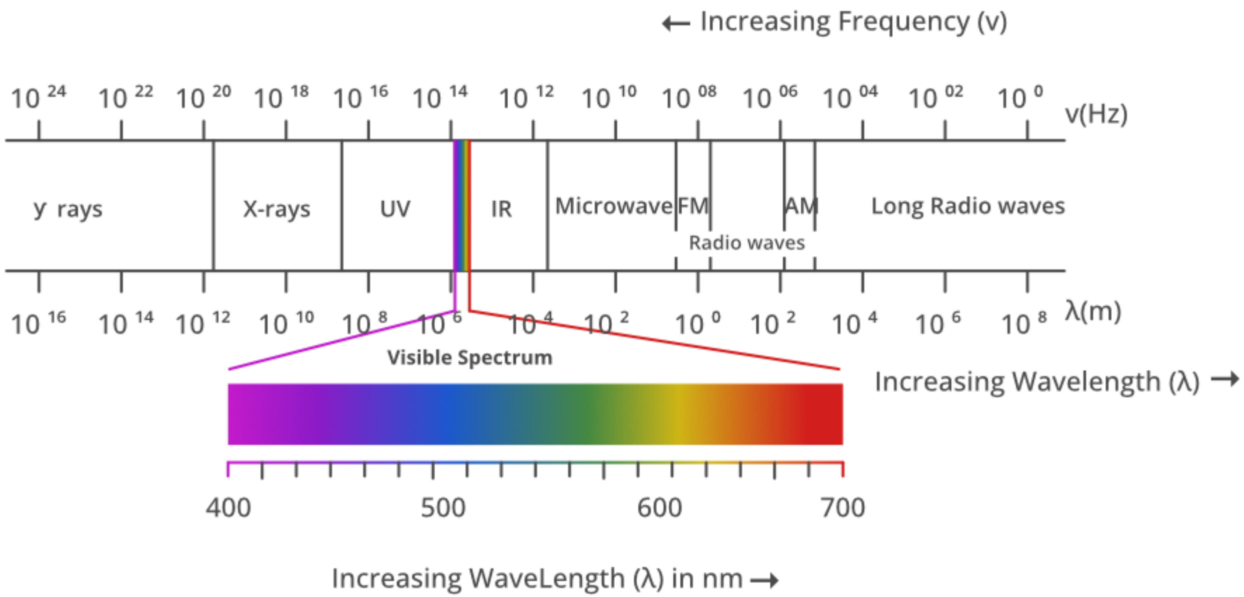
✓ Relation between the different mineral grains



Basics of optics

For optical mineralogy, we shall treat light as a wave phenomenon





V=fλ

V : velocity (m/s)

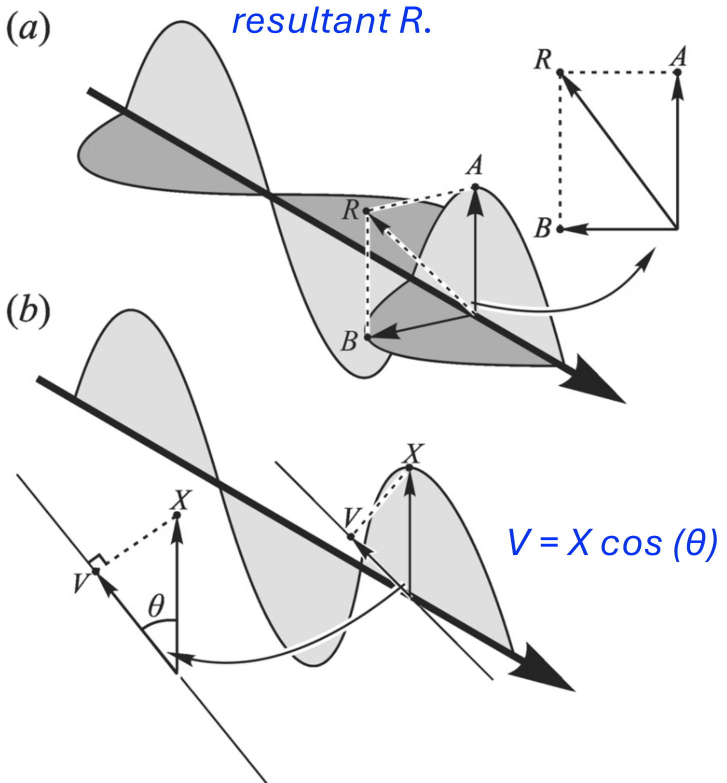
f : frequency (cycles/s)

λ : wavelength (m)

Basics of optics

Vector resolution of light waves.

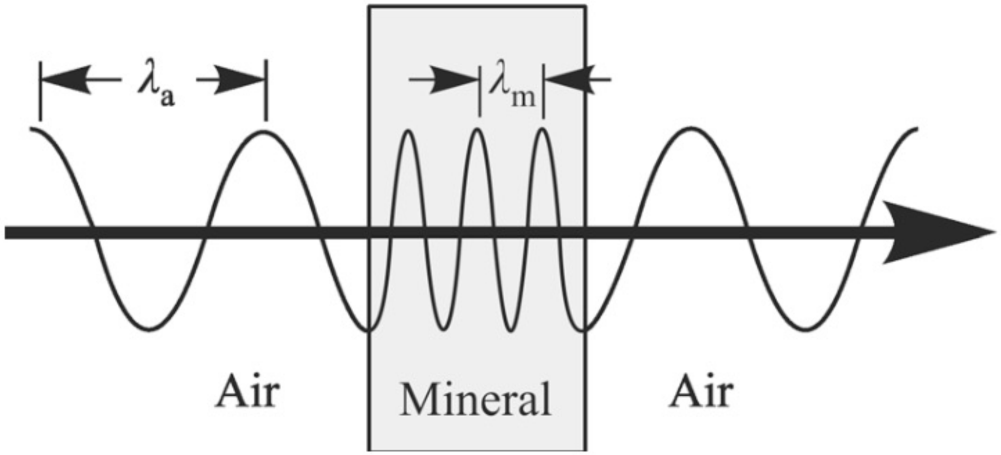
Waves A and B form resultant R.



V = X cos (θ)

A component V of wave X can be resolved in a new direction at angle θ from X.

Interaction of light with mineral



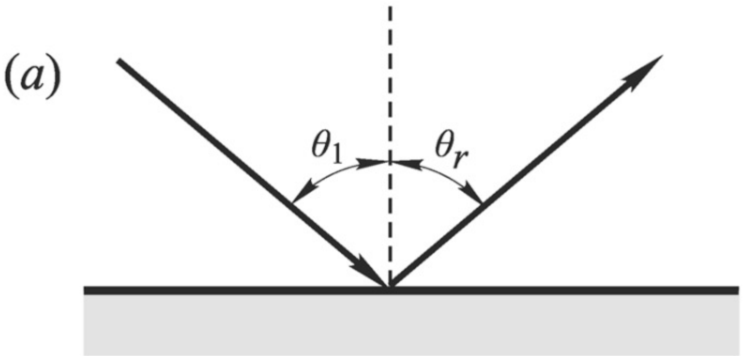
- ✓ *Light slows down and wavelength decreases*
- ✓ *Frequency remains the same*

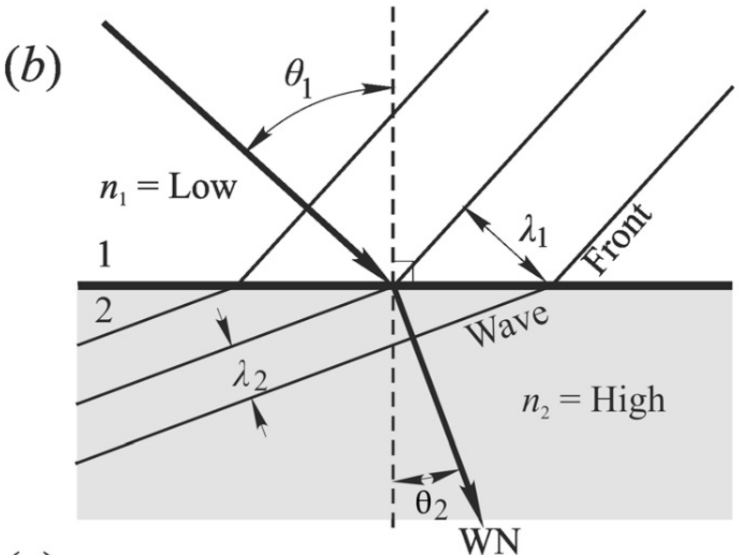
Refractive index

$$\boldsymbol{n = \frac{V_a}{V_m} = \frac{f\lambda_a}{f\lambda_m} = \frac{\lambda_a}{\lambda_m}}$$

Basics of optics

Reflection and refraction

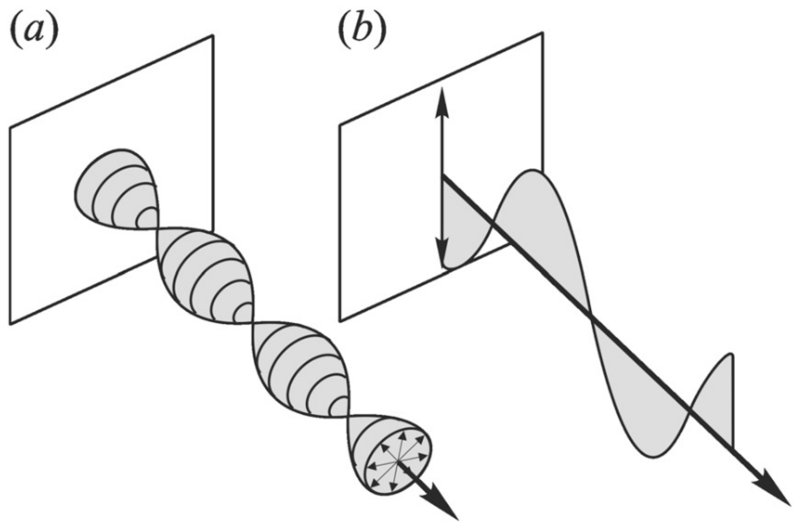




Snell's Law

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$$

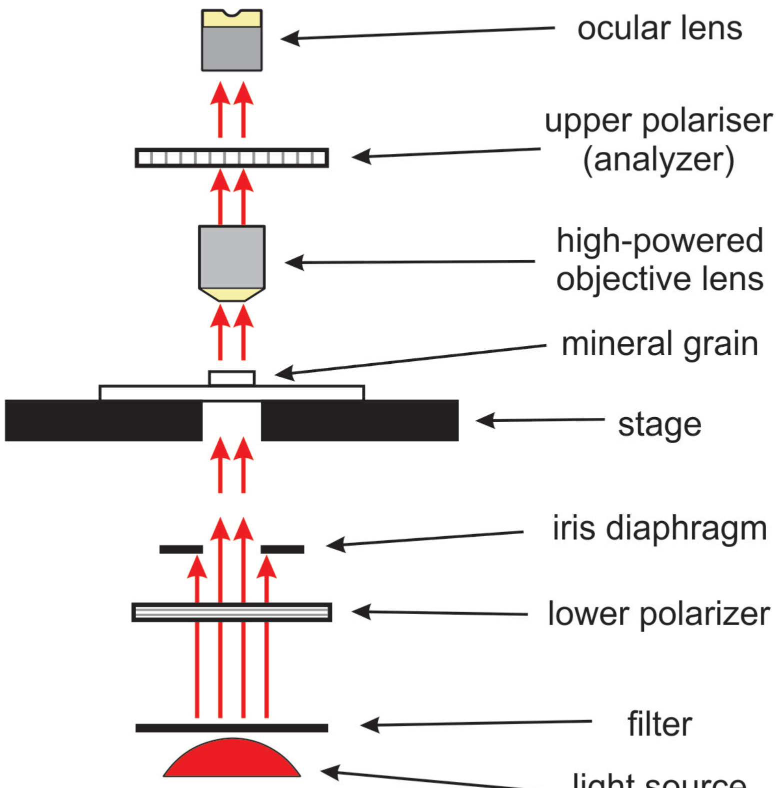
Polarized light



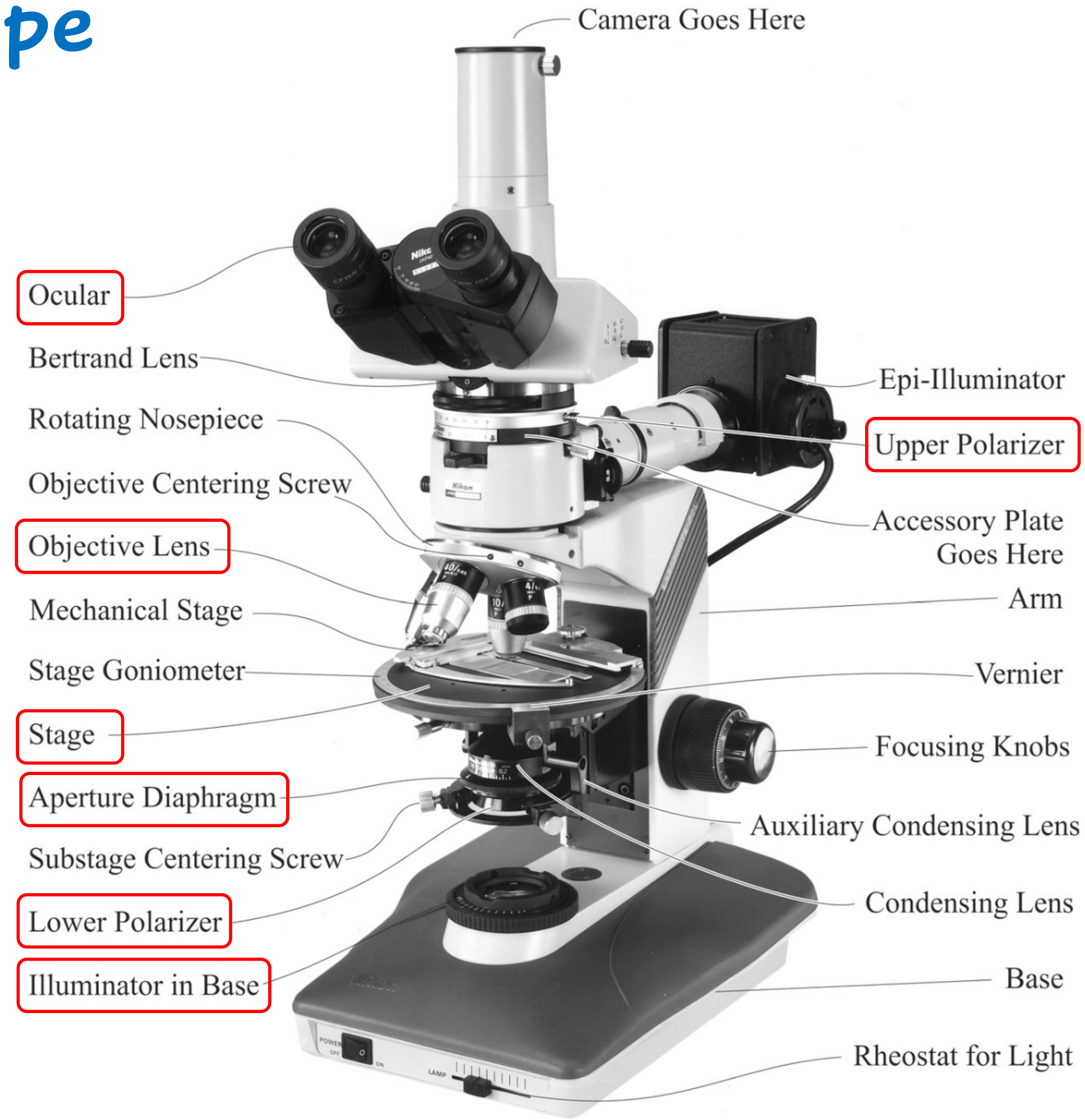
- ✓ Ordinary light coming directly vibrates in all directions at right angles to the direction of propagation – **Unpolarized light.**
- ✓ If the vibration of the light is constrained to lie in a single plane – **Plane polarized.**
- ✓ Vibration can be represented by a simple **sine wave.**

Petrographic Microscope

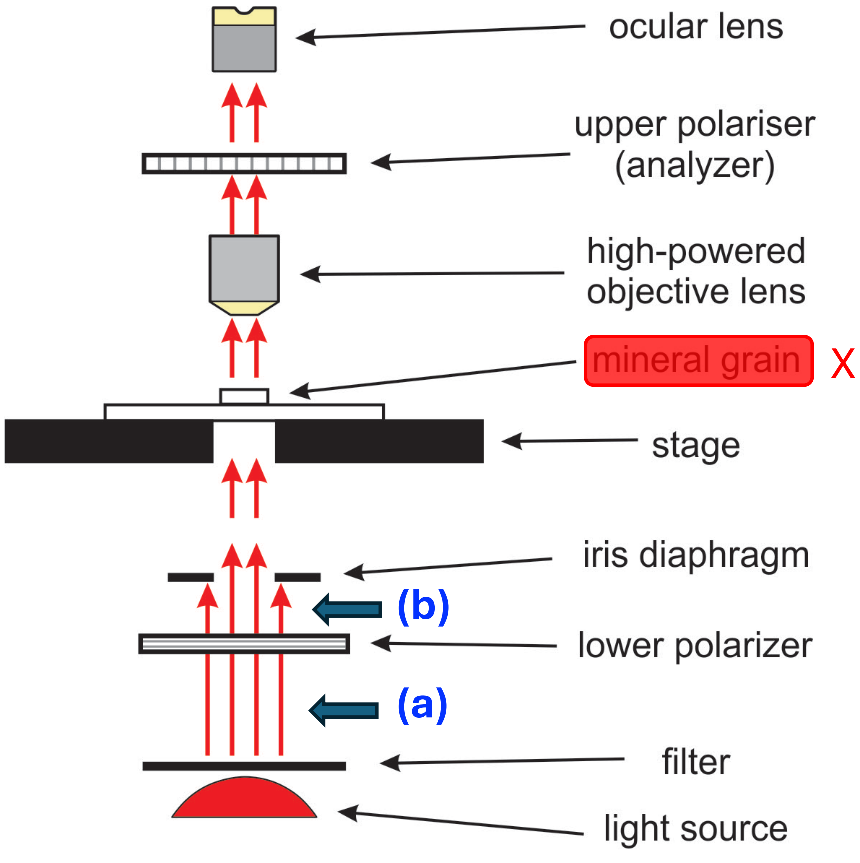
Fundamentals of a petrographic microscope



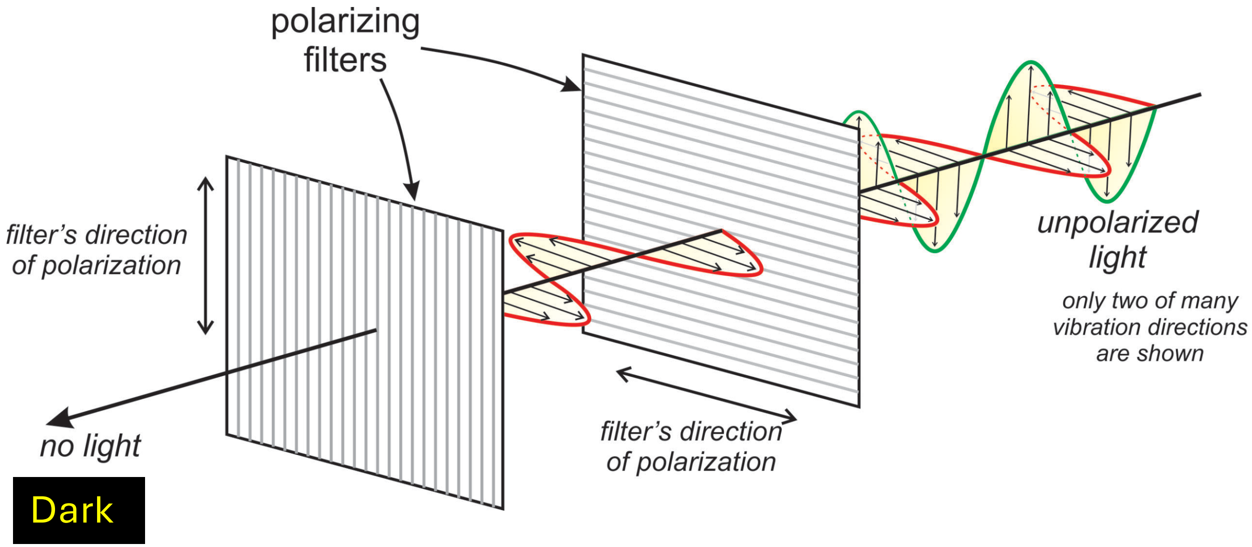
standard orthoscopic illumination

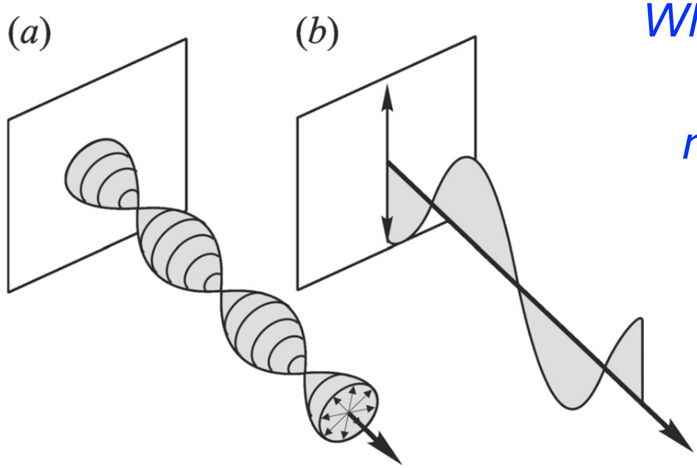


Petrographic Microscope



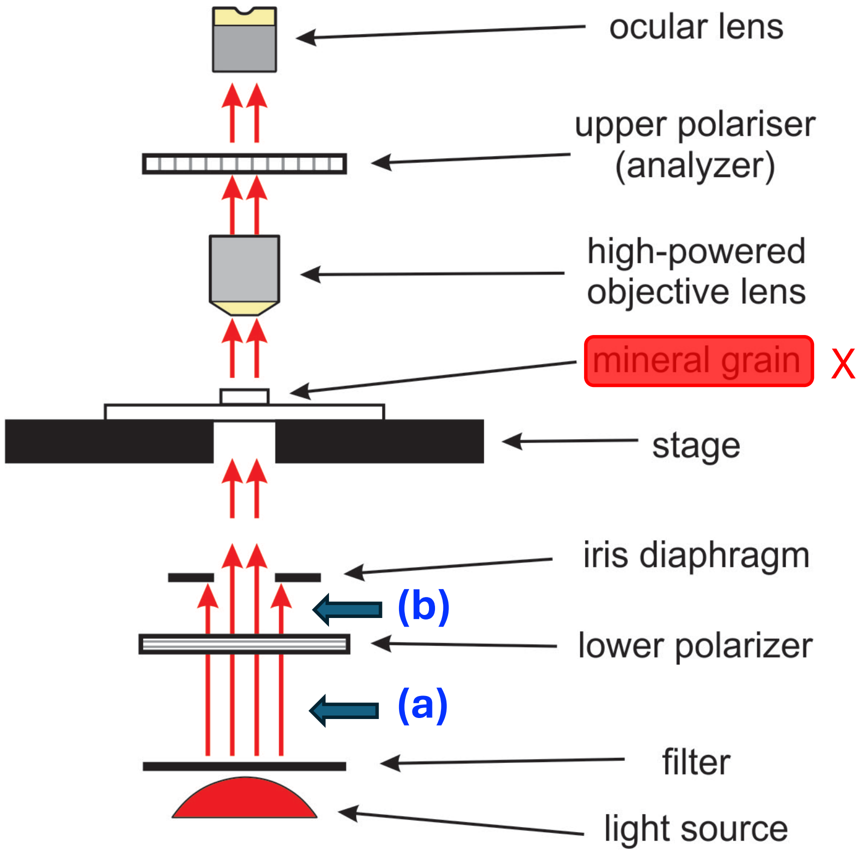
standard
orthoscopic
illumination





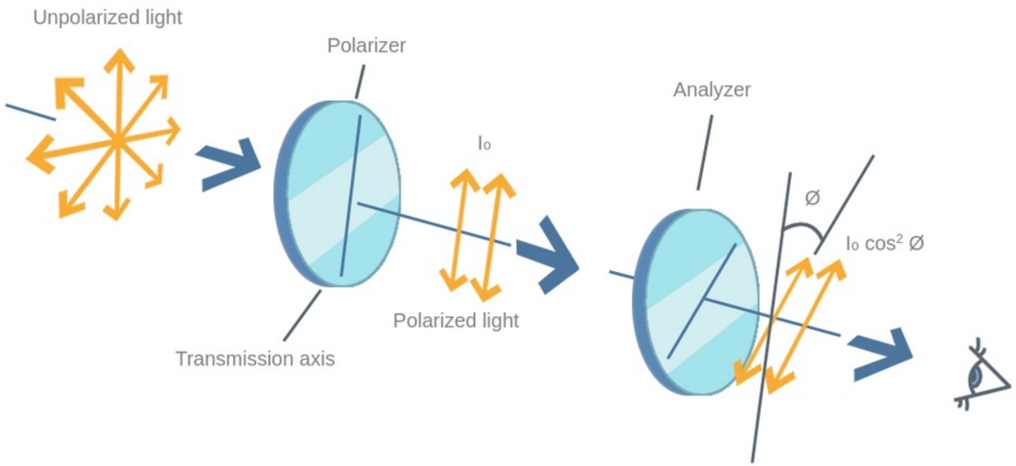
What happens when light passes through a microscope without a mineral grain?

Petrographic Microscope

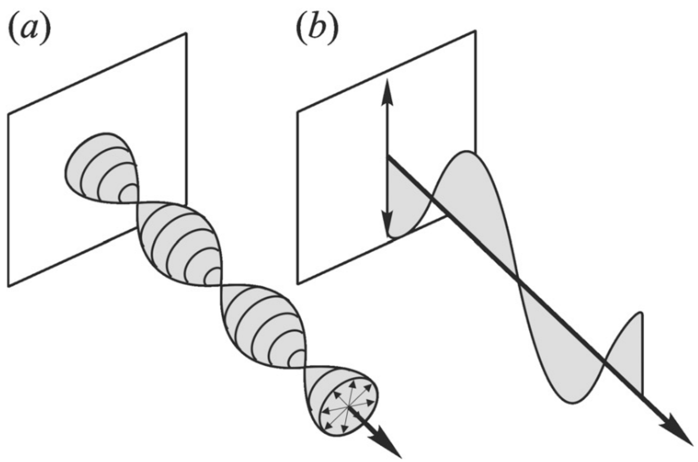


standard
orthoscopic
illumination

What happens if the two polarizers are not perpendicular?



If θ becomes 90°?



Isotropic and anisotropic mineral

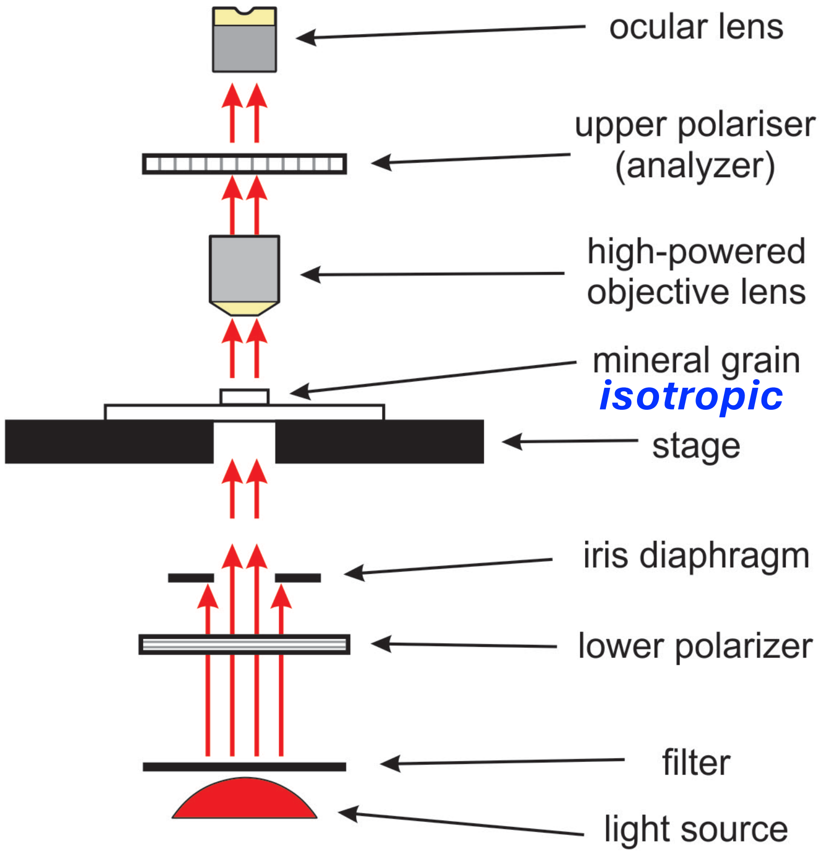
❑ Isotropic mineral

- An optically isotropic material is one in which the velocity of light is the same in all directions.
- The isotropic rock-forming materials include volcanic glass and minerals belonging to a specific crystal system.
- In these materials, electron density is the same in all directions, at least on average.
- The strength of the electric field with which the electric vector of light interacts also is the same regardless of direction.
- Light velocity is same in all directions.

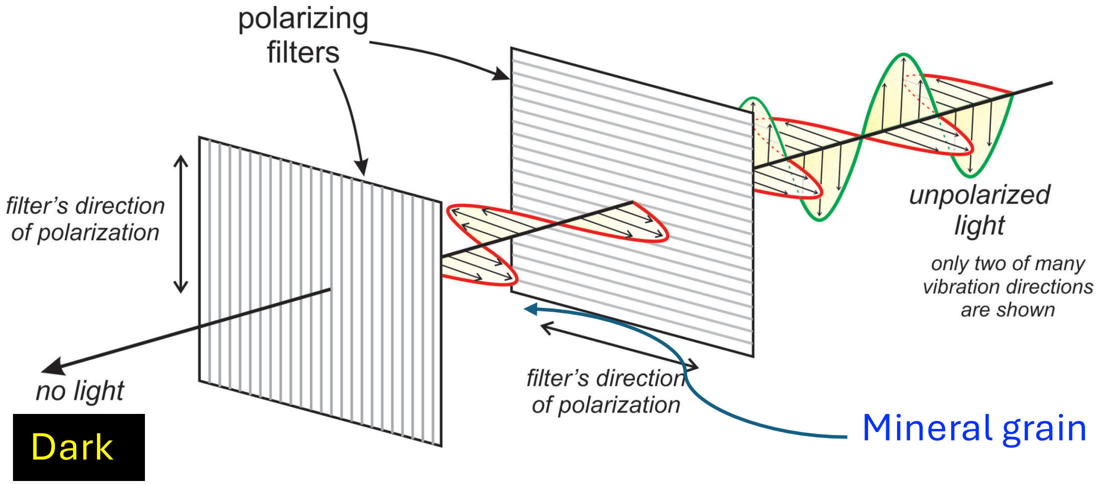
❑ Anisotropic mineral

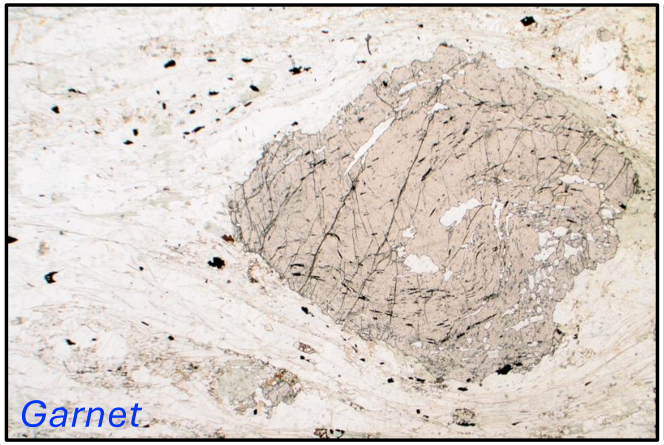
- An **optically anisotropic** material is one in which the velocity of light is different in different directions.
- The electron density varies with direction.
- The electrons of the atoms/ions in these minerals are not able to interact with light in the same way in all directions.
- The velocity and absorption characteristics (color) of light vary with direction.

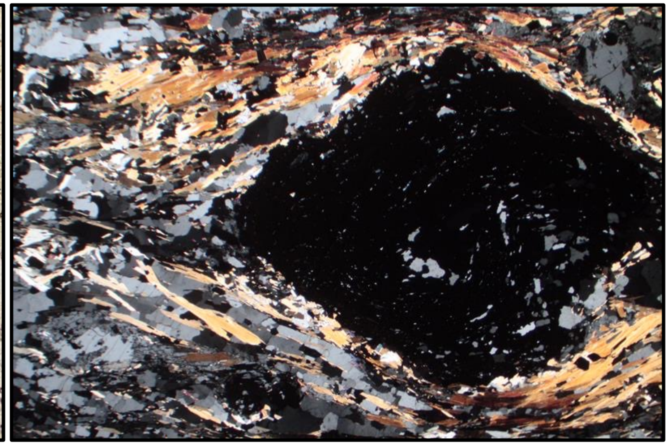
Isotropic mineral



standard
orthoscopic
illumination





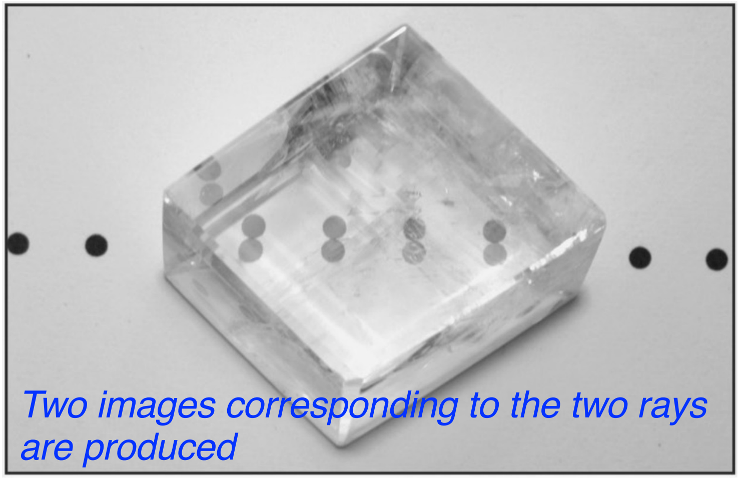


Plane Polarized Light (PPL)

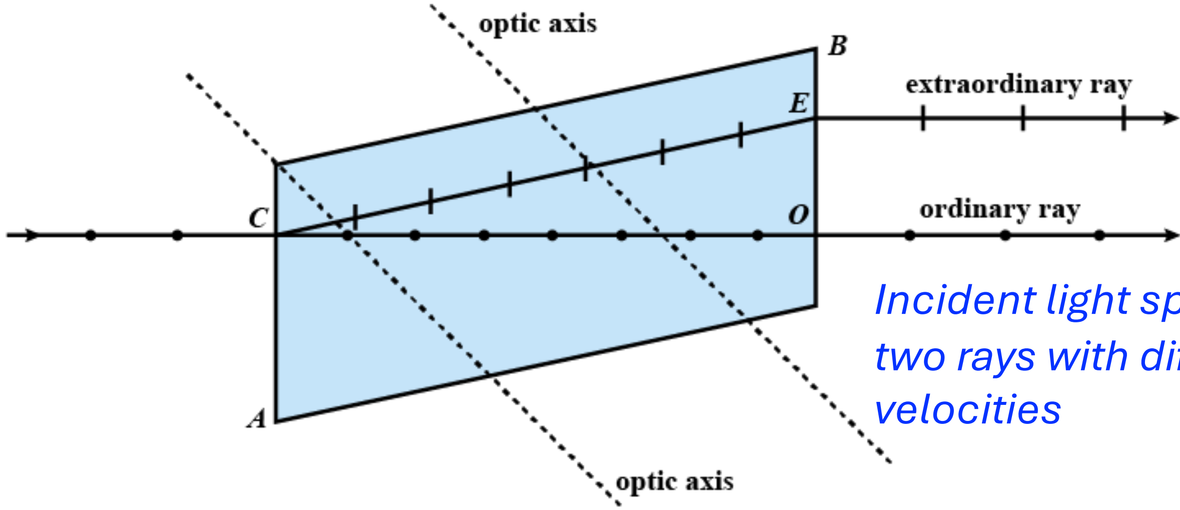
Crossed Polarized Light (XPL)

Light through an anisotropic mineral

Anisotropic minerals show double refraction



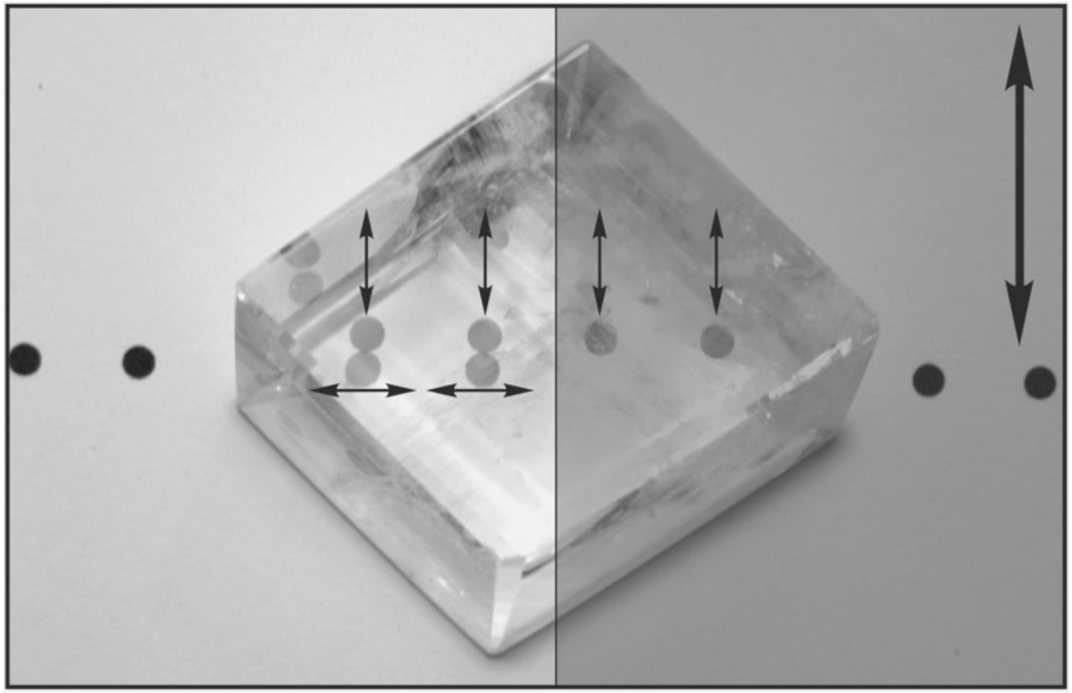
Two images corresponding to the two rays are produced

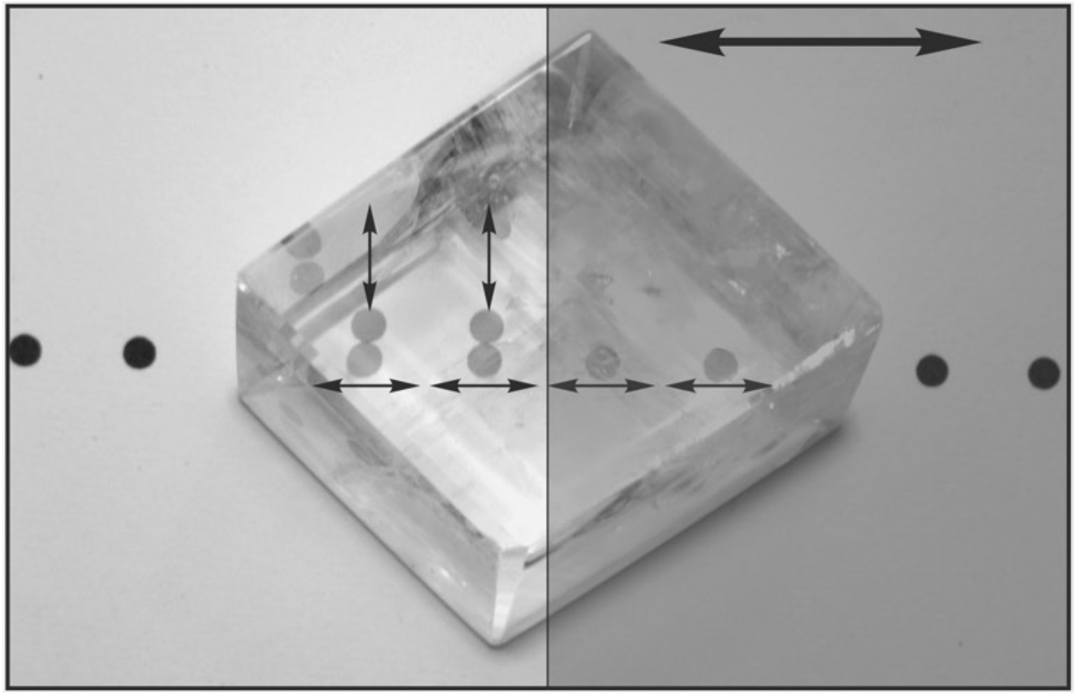


Incident light splits into two rays with different velocities

- ***Ordinary ray (o-ray)*** follows Snell's law. Its velocity is same in every direction
- ***Extraordinary (e-ray)*** does not obey Snell's law. Its velocity is different in different directions.
- These e- and o-rays are vibrating at ***right angles*** to each other.
- Every anisotropic mineral has one or two directions, called ***optic axes***, along which the light is ***not*** split into two rays.

Double refraction in calcite



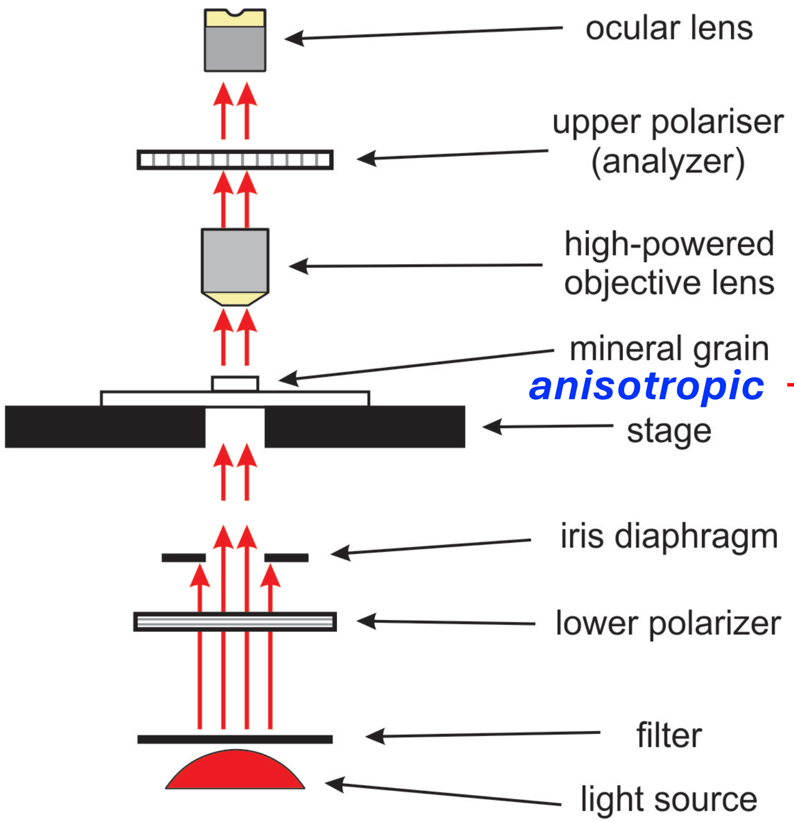


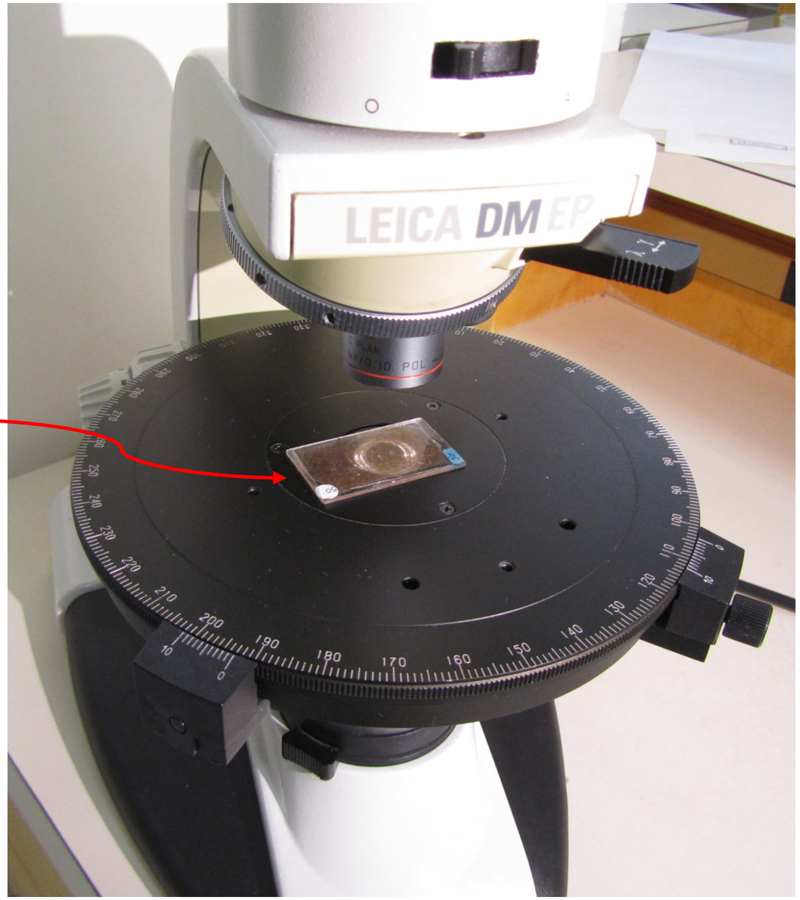
- A polarizing film whose vibration direction is parallel to the short diagonal of the rhomb passes one set of dots and absorbs the other.

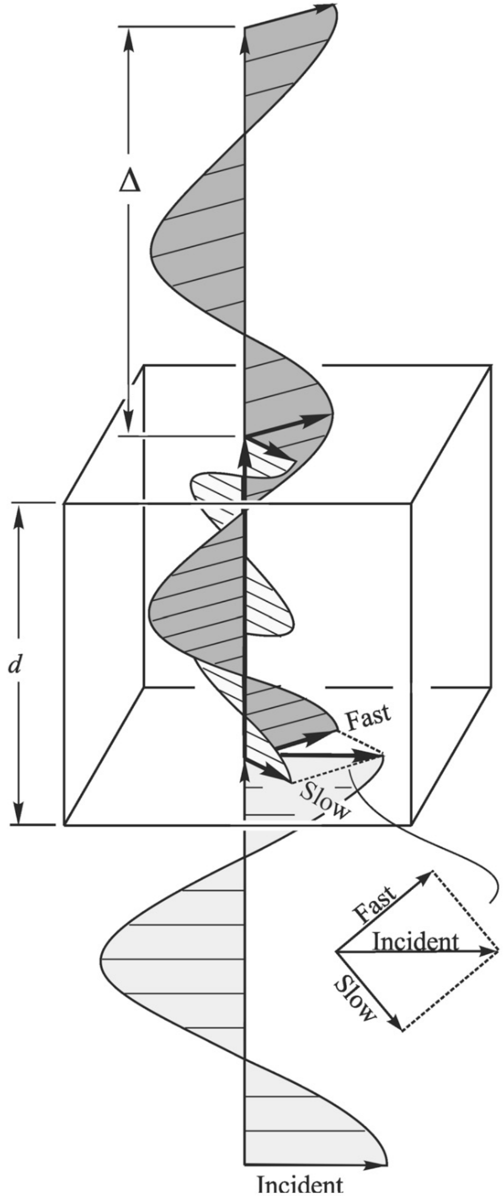
- The polarizing film is rotated 90°.
- The first set of dots is absorbed and the other passes.
- In intermediate orientations, both sets of dots are visible with subdued brightness.

The two rays must therefore be plane polarized and vibrating at right angles to each other.

Double refraction





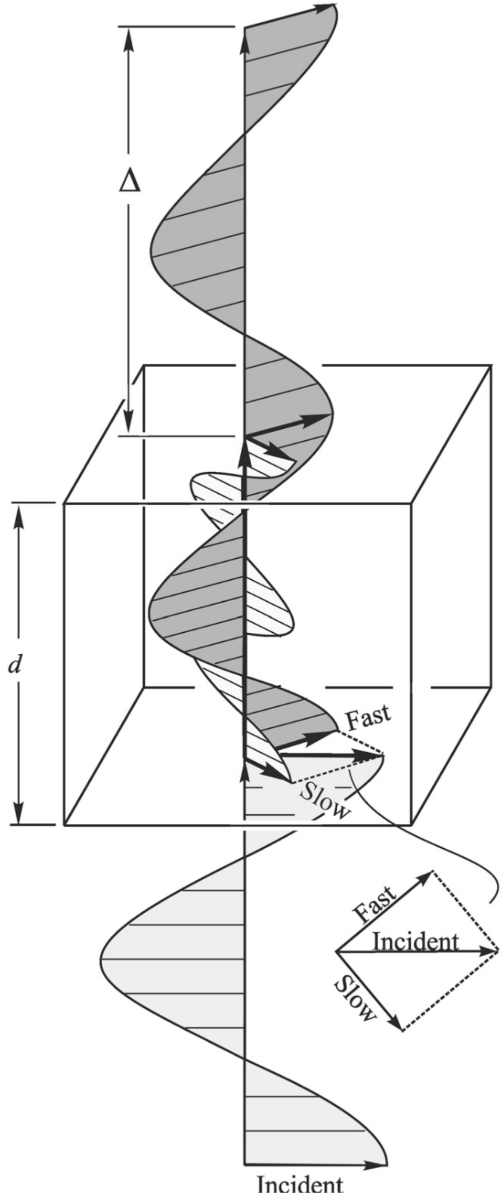


Double refraction

- If the light velocity of the two rays is determined by measuring indices of refraction, it will be found that one ray is ***faster*** than the other.
- The ray with the ***greater velocity*** (V_f) and ***lower refractive index*** (n_f) is called the ***fast ray***
- The ray with the ***lower velocity*** (V_s) and ***higher refractive index*** (n_s) is called the ***slow ray***.
- The two rays vibrate ***perpendicular*** to each other.

$$n_f = \frac{V_0}{V_f} \qquad n_s = \frac{V_0}{V_s}$$

- Due to the difference in index of refraction, the slow ray lags behind the fast ray.

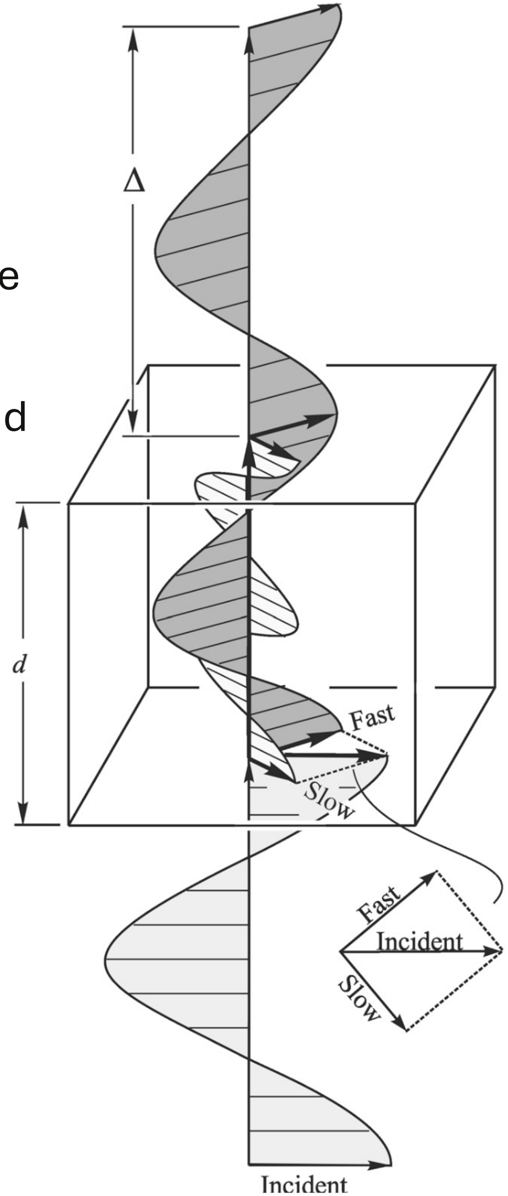


Double refraction

- During the *time taken by slow ray* to pass through the mineral, the fast ray will pass through the mineral plus an *additional distance* called the ***retardation (Δ)***.
- The *retardation remains constant* after the slow and fast rays have exited into the air above the mineral grain because both have the same velocity there.
- The magnitude of the retardation depends on the thickness of the mineral (d) and on the difference in index of refraction of the slow ray (n_s) and fast ray (n_f) in the mineral.

$$\Delta = d\,(n_s - n_f) = d\,(\delta)$$

- (δ) is the birefringence equal to the value (ns − nf).
- The numerical value of birefringence depends on the direction followed by the light through the mineral.
- Parallel to an optic axis: zero birefringence (Mineral appears dark).
- Other directions show a maximum birefringence, and **most show an intermediate value**.
- ***The maximum birefringence is a useful diagnostic property of minerals.***



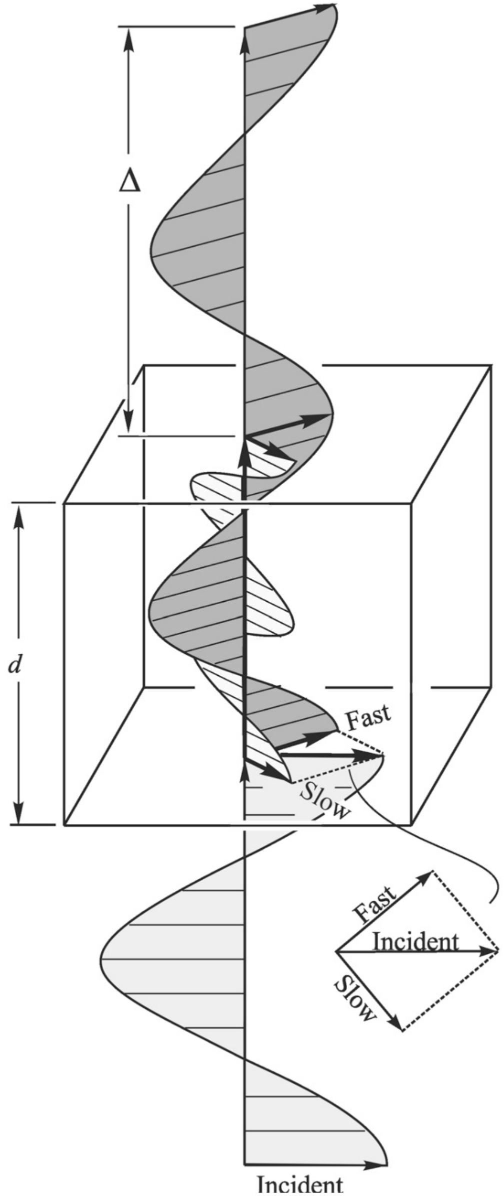
Double refraction

- Time taken by slow ray to pass through the mineral, the fast ray will pass through the mineral plus an additional distance called the retardation (Δ).
- The retardation remains constant after the slow and fast rays have exited into the air above the mineral grain because both have the same velocity there.
- The magnitude of the retardation depends on the thickness of the mineral (d) and on the difference in index of refraction of the slow ray (n_s) and fast ray (n_f) in the mineral.

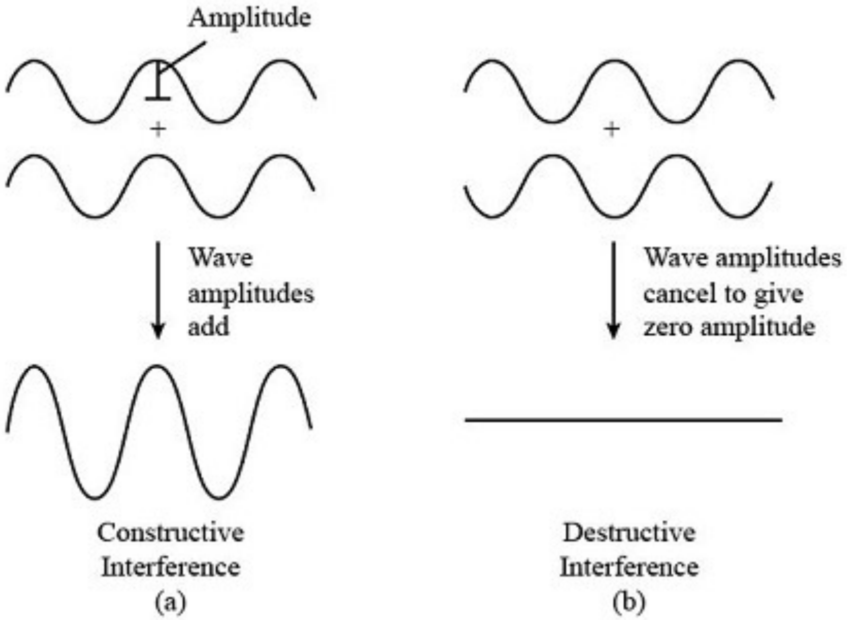
$$\Delta = d\,(n_s - n_f) = d\,(\delta)$$

$$t = \frac{d}{v_s} = \frac{d}{v_f} + \frac{\Delta}{V_0} \Rightarrow \Delta = d\left(\frac{V_0}{v_s} - \frac{V_0}{v_f}\right),$$

$$\Delta = d(n_s - n_f)$$

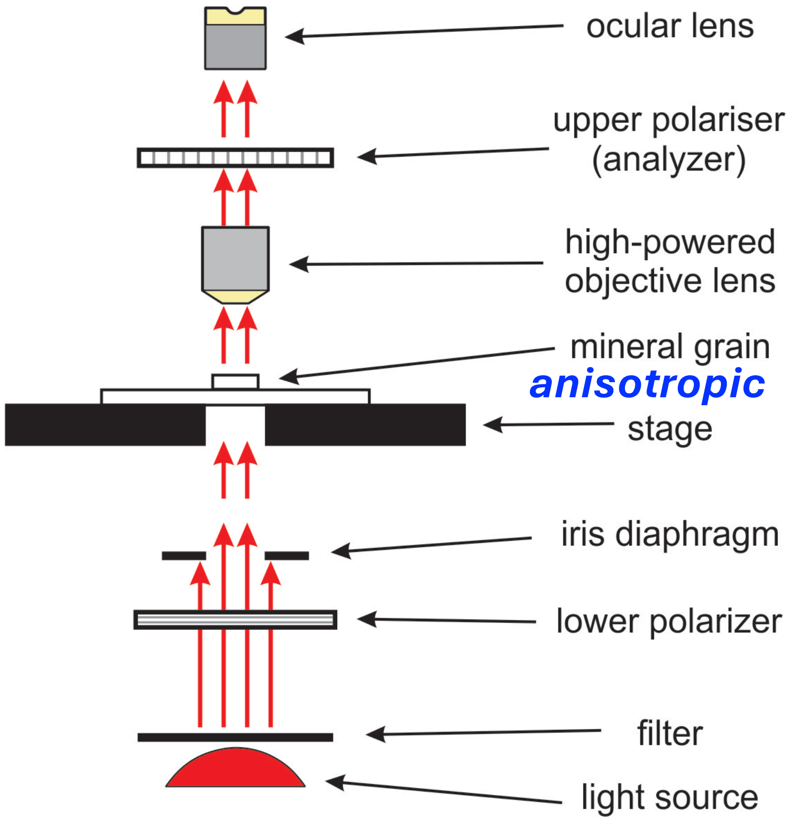


Interference of light waves



Interference color: The color seen between crossed polarizers, produced as a consequence of light being split into two rays on passing through the mineral.

Components of the two mutually perpendicular rays interfering along a single plane.



Interference of light waves

- ❑ **Case 1**: the slow ray is retarded an integer number of wavelengths relative to the fast ray

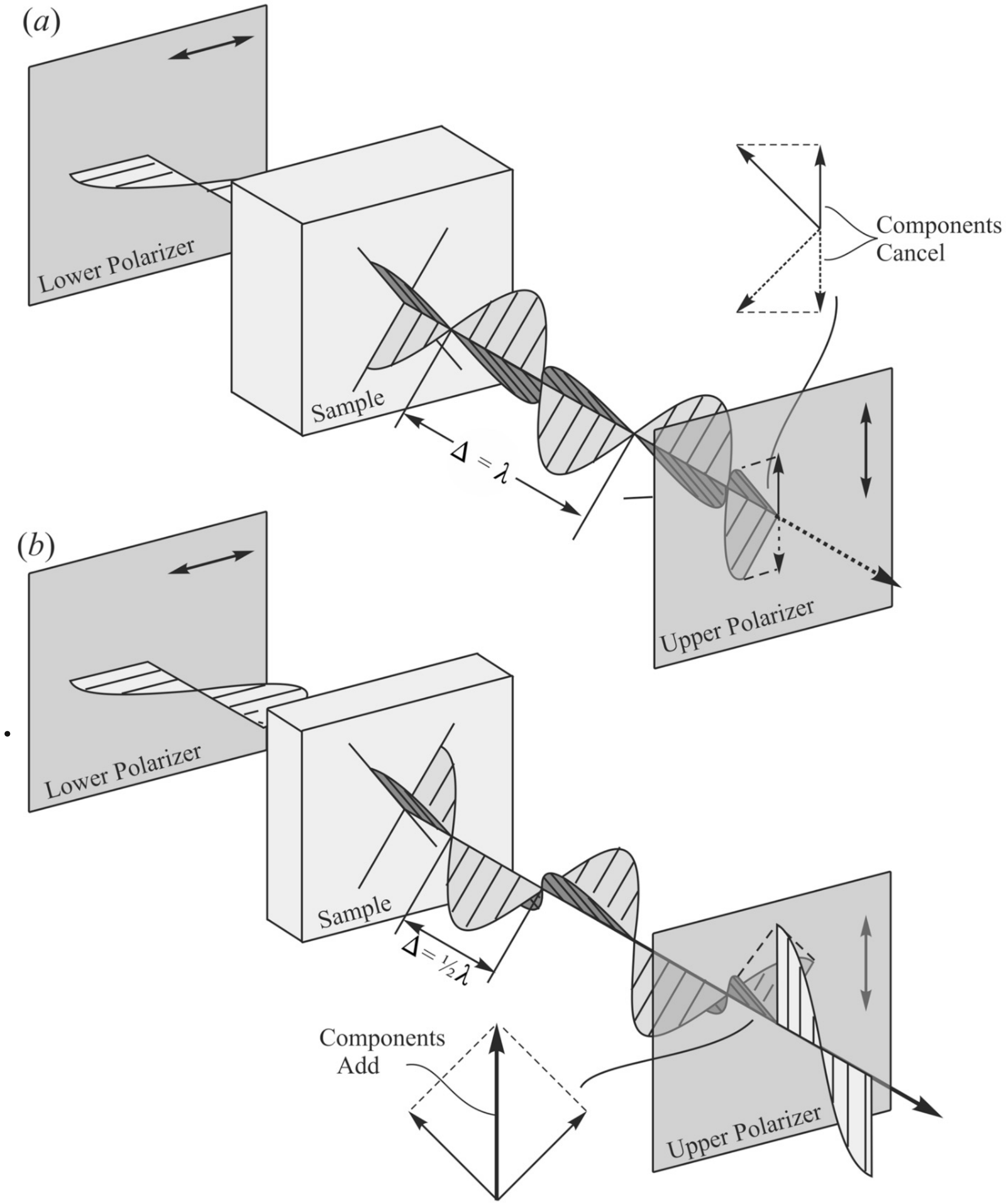
  $\mathbf{\Delta = i\,\lambda}$ *i : integer; λ : wavelength*

- Components of the two rays resolved into the vibration direction of the upper polarizer → equal magnitude; opposite directions → ***cancel each other***
- No light passes the upper polarizer → mineral grain appears ***dark***.

- ❑ **Case 2:** the retardation is equal to one-half wavelength.

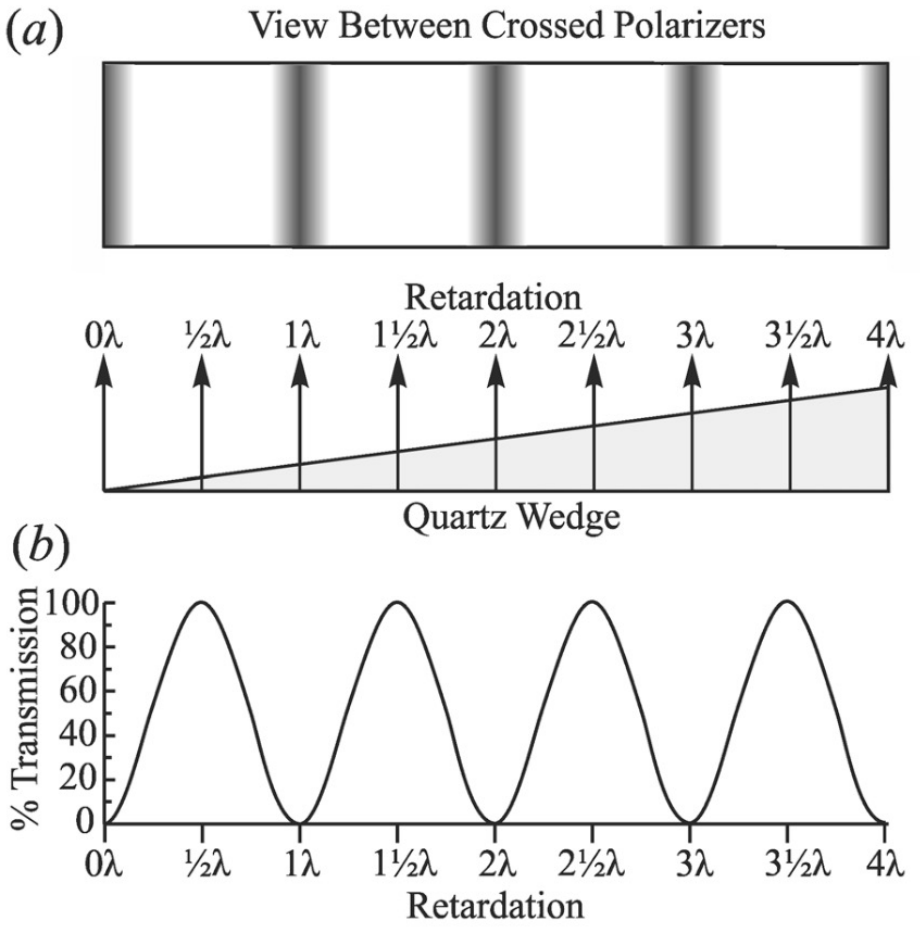
  $\Delta = \left(i + \frac{1}{2}\right)\lambda$ *i : integer; λ : wavelength*

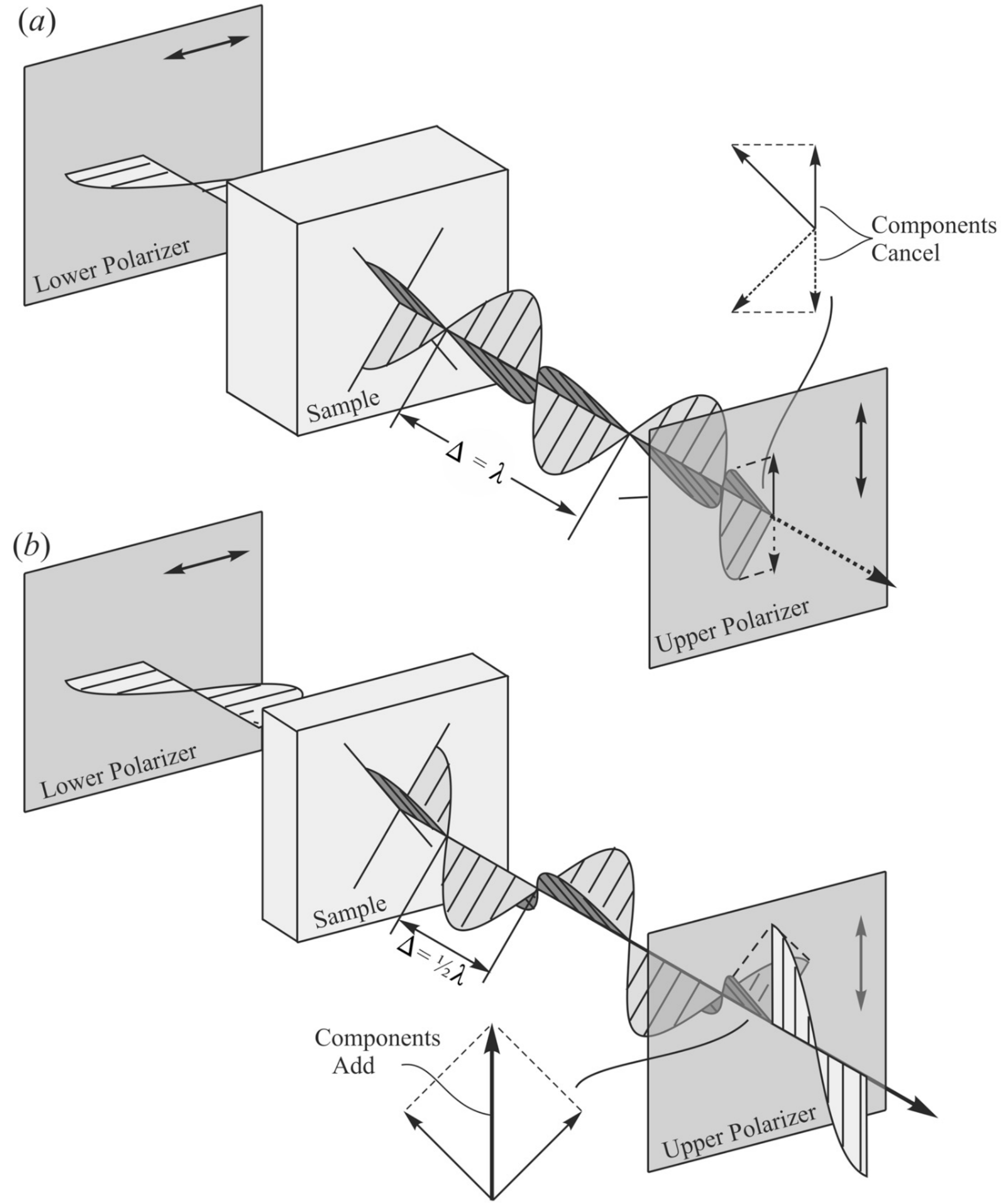
- The resolved components are both in the same direction → light constructively interferes → light passes the upper polarizer.
- The observed color is the ***interference color***



Interference of light waves

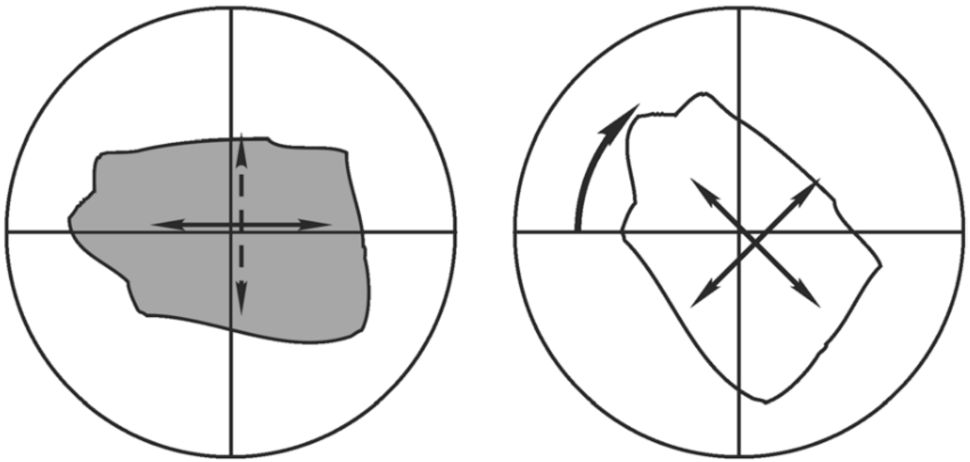
- ❑ ***Viewing a quartz wedge under crossed polars***



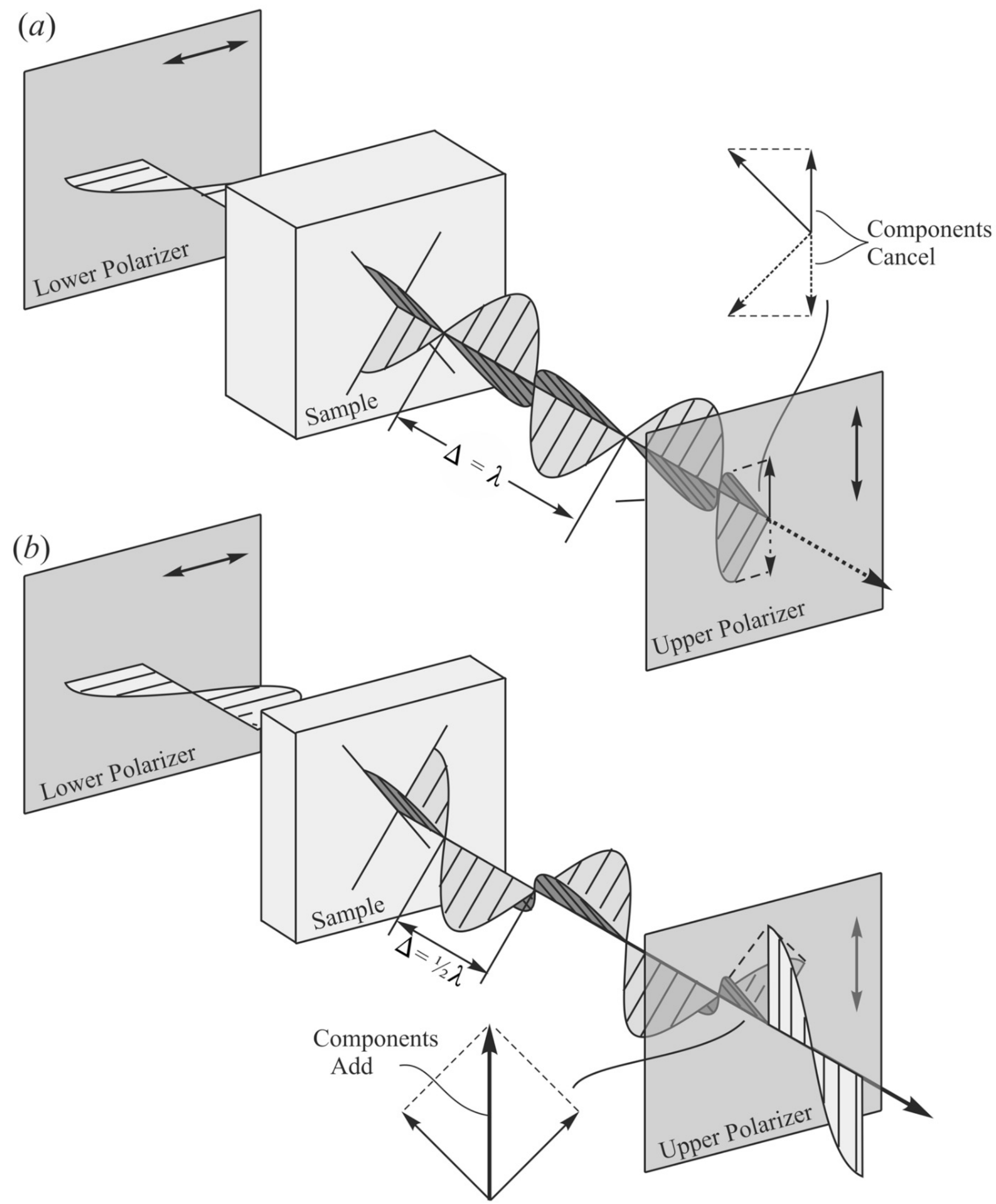


Extinction

What happens when we rotate the stage?



(a) (b)

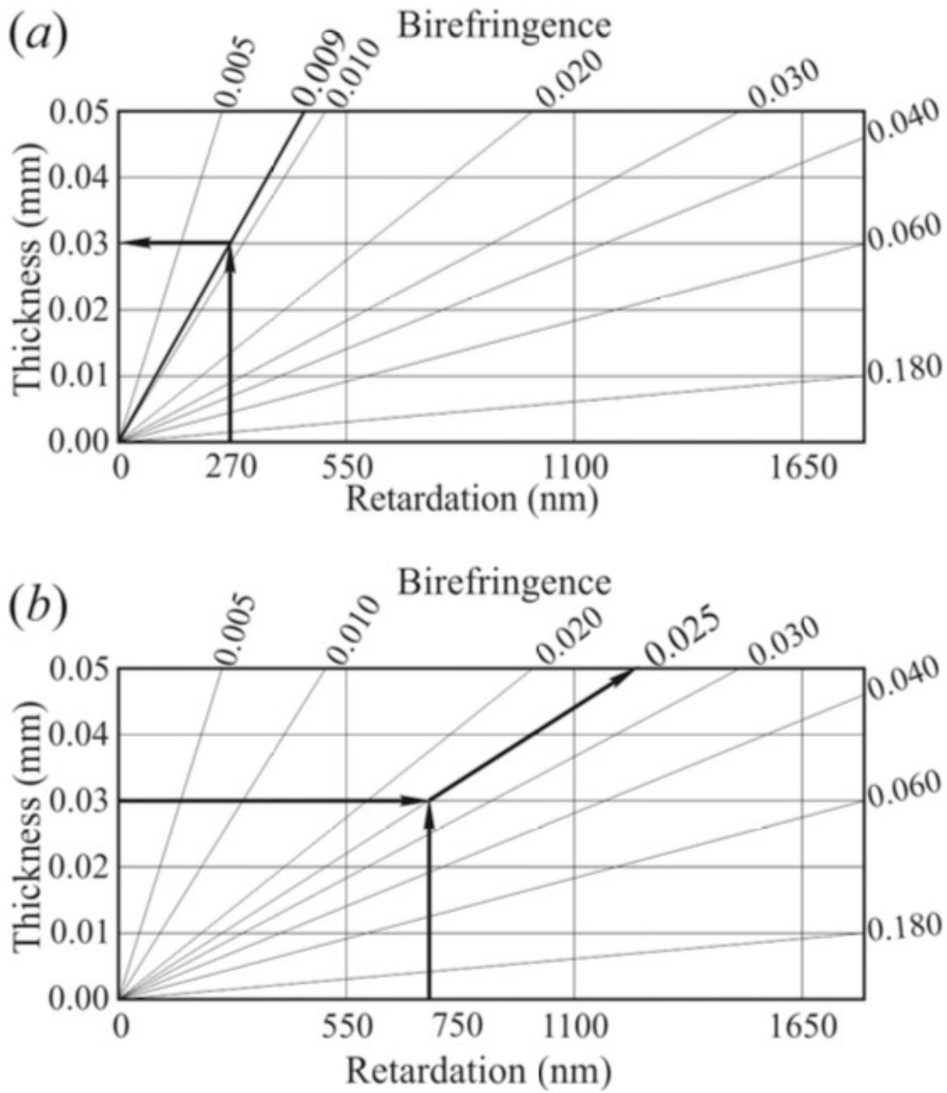


All anisotropic minerals go dark or extinct between crossed polarizers once in every 90° of stage rotation.

The interference color does not change with rotation. It gets brighter and dimmer, because the retardation between the two rays remains constant.

Use of interference color chart

- The interference color chart shows the interference colors produced for **retardations (path differences) between 0 and 1800 nm.** These values are plotted along the lower edge of the diagram.
- Thickness is plotted along the y-axis
- Birefringence is plotted along the upper and right edge of the diagram.
- This color sequence is conveniently divided into orders, with the breaks between orders occurring **every 550 nm** of retardation.
- First- and second-order colors are most vivid; higher-order colors are progressively more and more washed out.
- Above the fourth order, the colors degenerate into a creamy white.



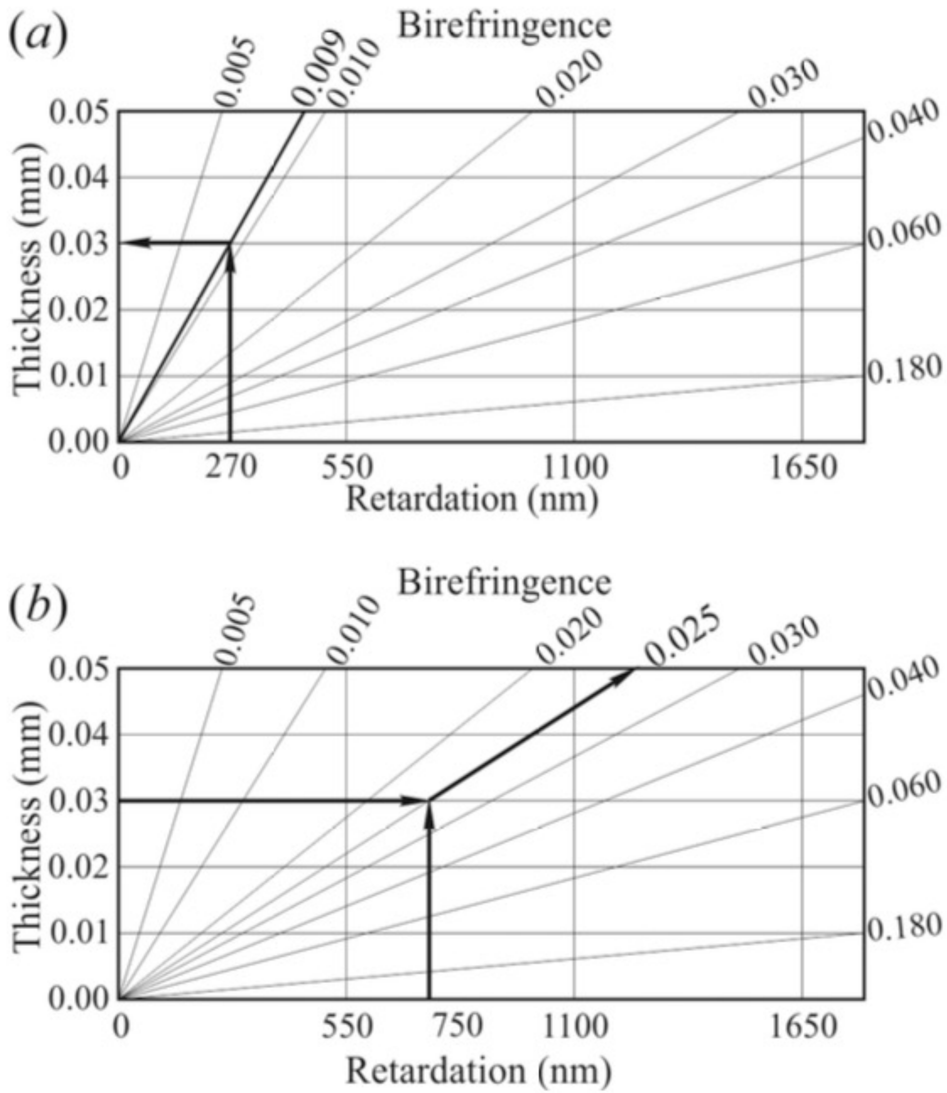
Use of interference color chart

Used for:

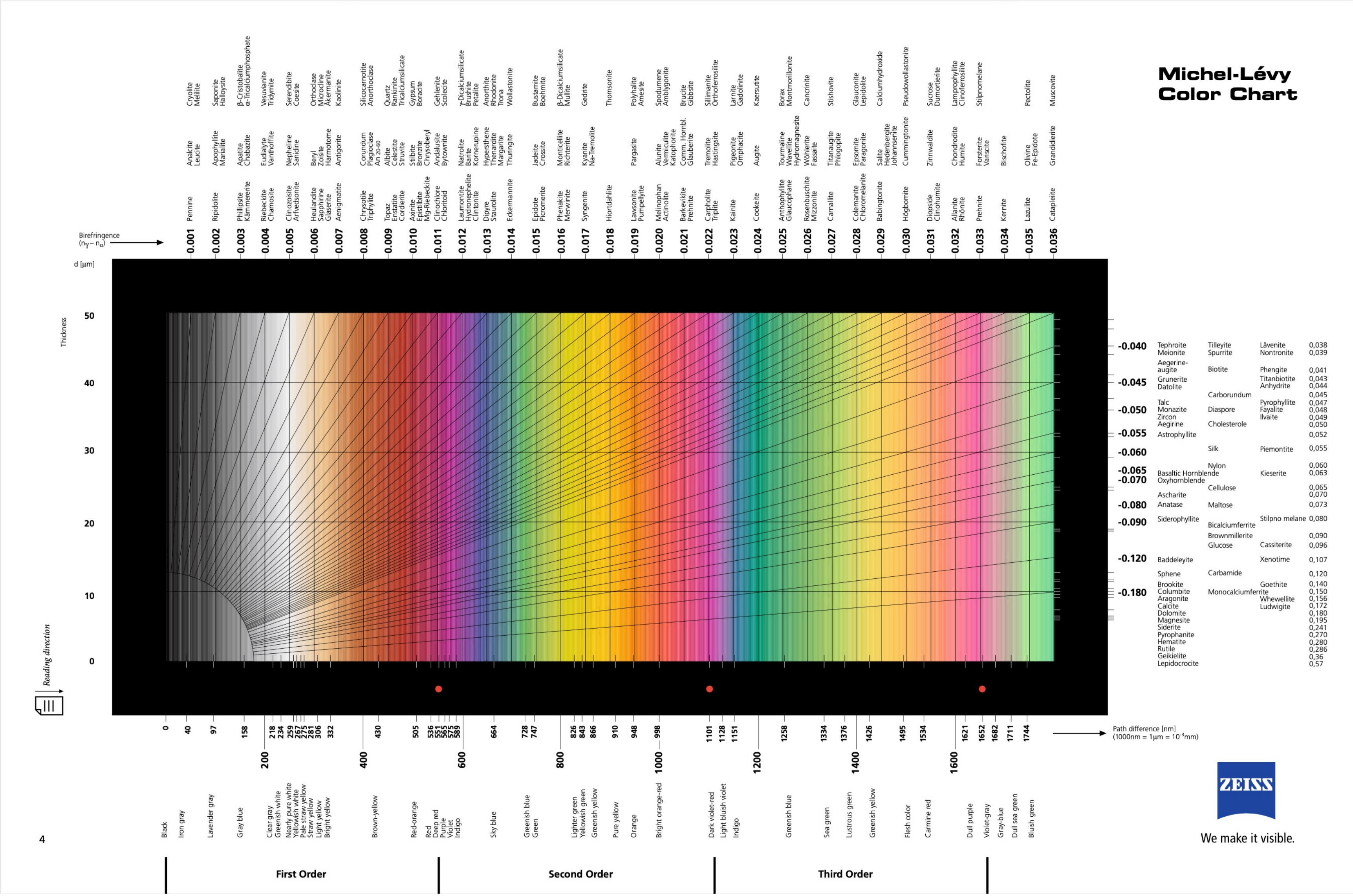
- Determination of retardation between the slow and fast rays.
- Determination of thickness

(a) Thickness is indicated by the horizontal line that goes through the point where birefringence and interference color intersect.

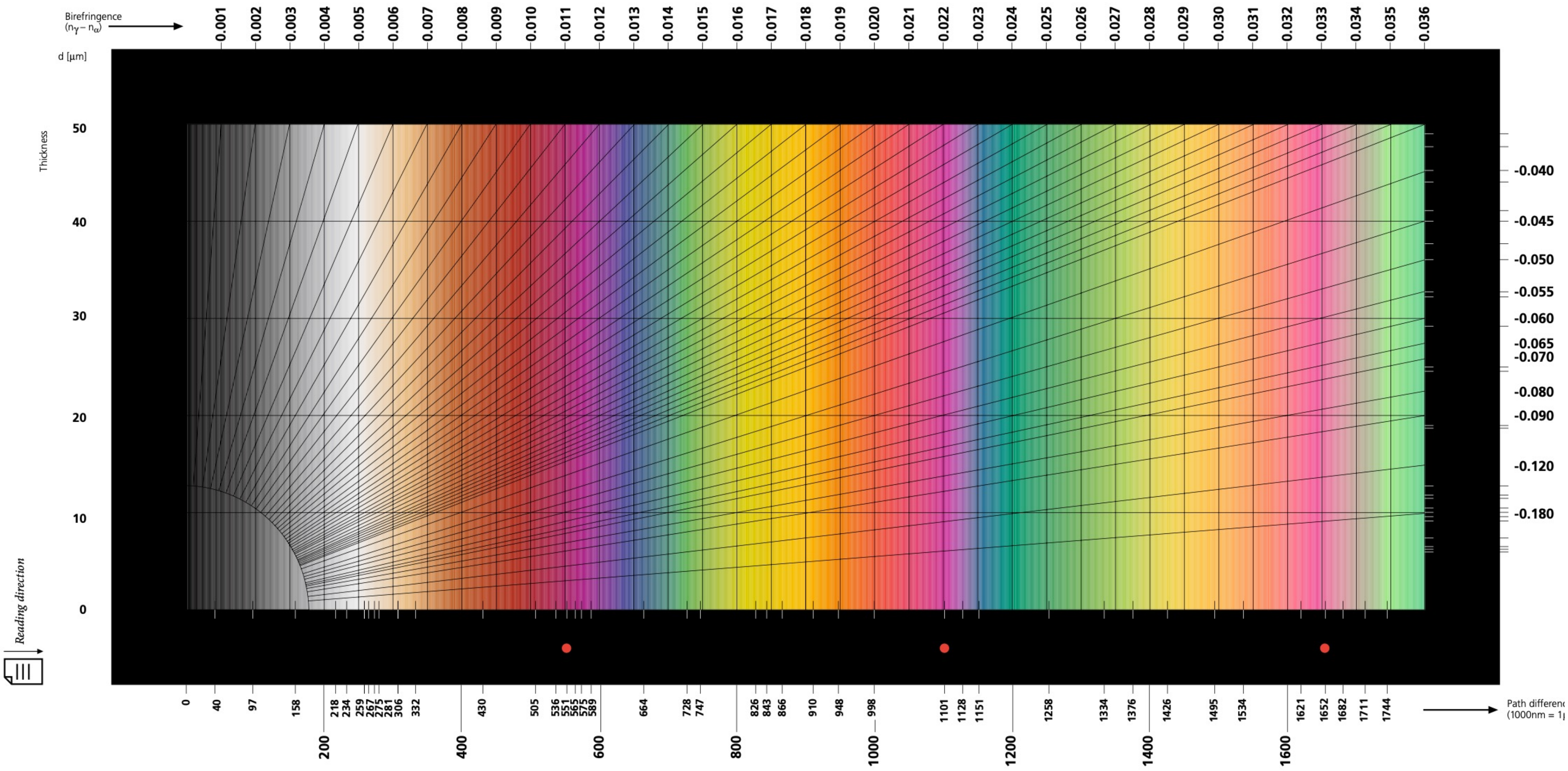
(b) Birefringence is indicated by the diagonal line that goes through the intersection of interference color (retardation) and thickness.



Michel-Levy Color Chart



Michel-Levy Color Chart



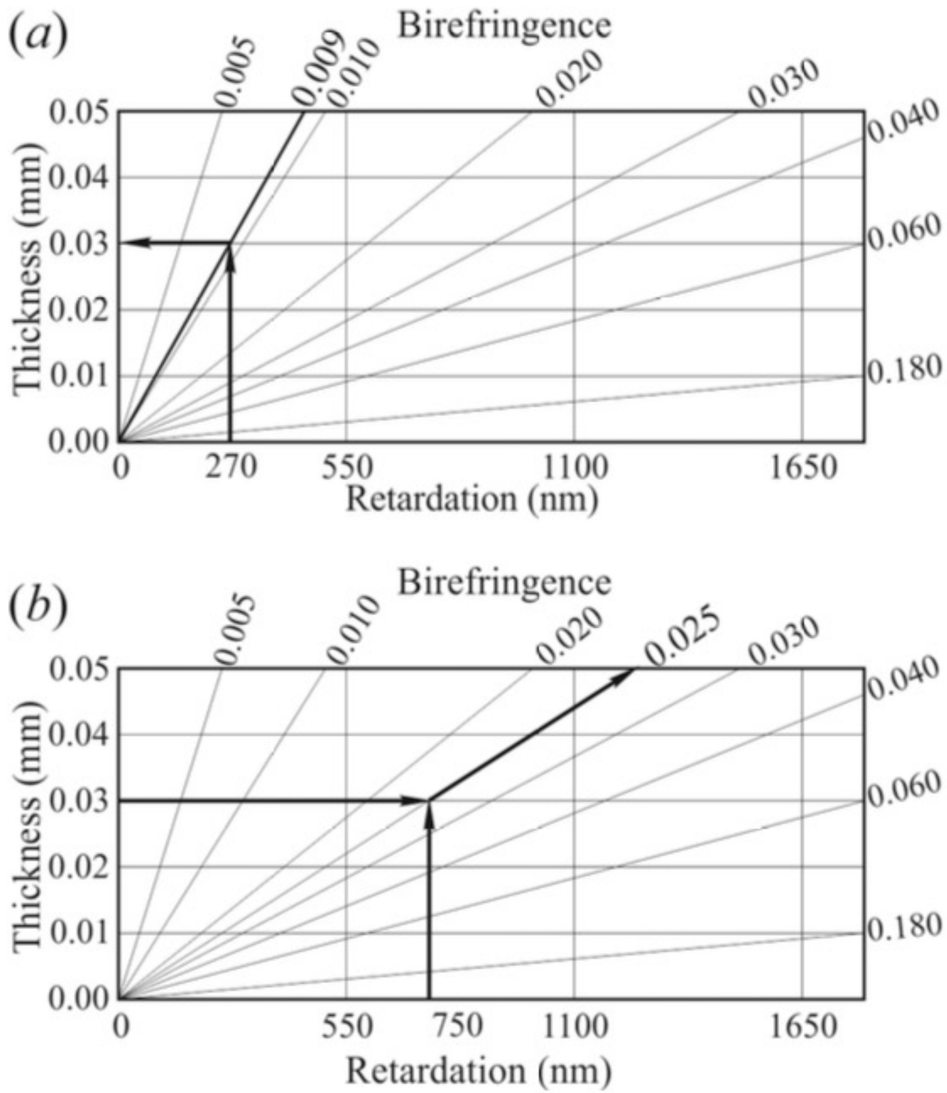
Determining thickness

Example: Quartz

- Scan the slide to find grains of quartz that display the highest interference color → farthest to the right on the interference color chart.
- A grain whose c axis is parallel to the microscope stage (horizontal) will display the maximum birefringence.
- Only these grains are oriented to display the known 0.009 (maximum) birefringence
- Identify the highest interference color displayed by the quartz and find it on the interference color chart.
- Read the retardation corresponding to that color from the bottom edge of the chart.
- If, for example, the color is first-order white with a tinge of yellow, the retardation is 270 nm.

$$\Delta = d\,(n_s - n_f) = d\,(\delta)$$

$$d = \frac{270\ \text{nm}}{0.009} = 30{,}000\ \text{nm} = 0.03\ \text{mm}$$

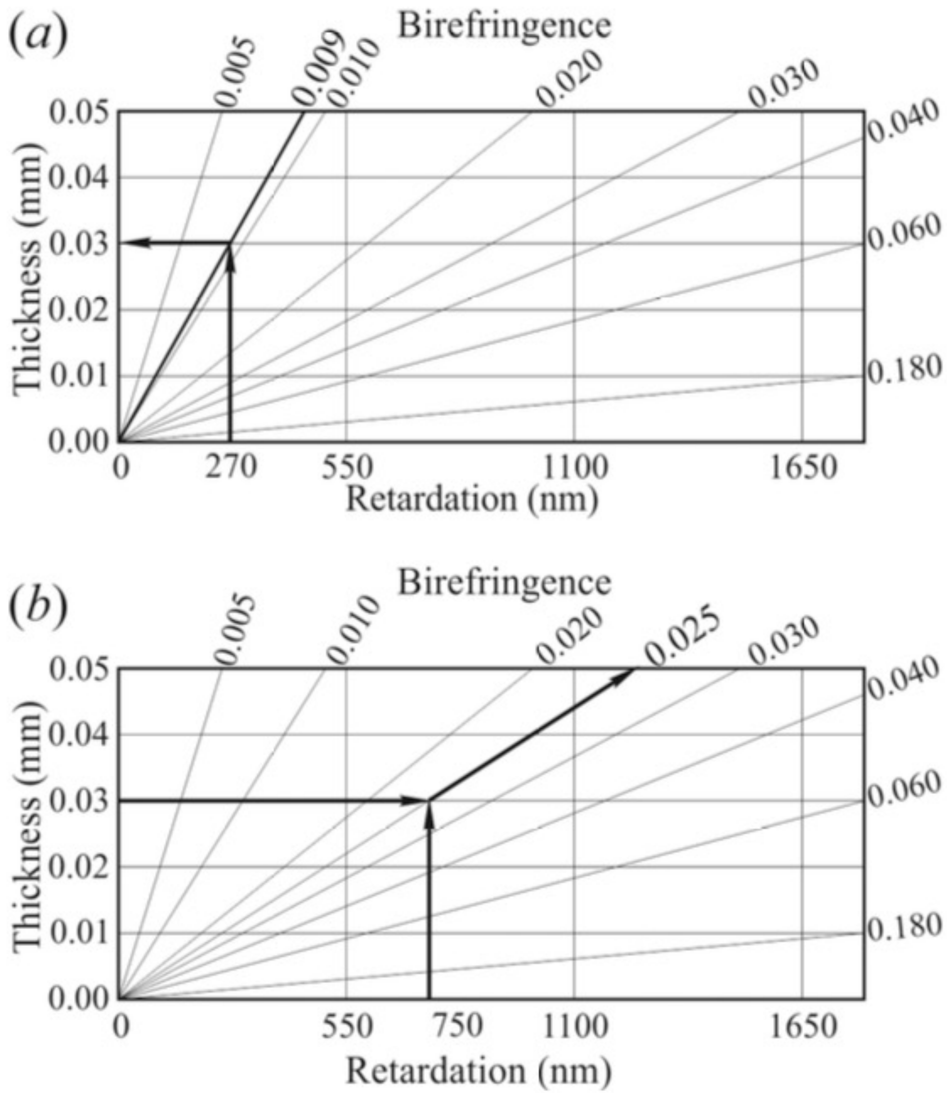


Determining birefringence

- The maximum birefringence of a mineral is a very useful diagnostic property.
- It is easy to measure in thin sections whose thickness is known.

For an unknown mineral:

- Scan the thin section to find a sample of the unknown mineral whose interference color is highest, i.e. farthest to the right on the interference color chart.
- Only these grains are oriented to display the maximum birefringence
- Identify that interference color, find it on the interference color chart.
- Read the retardation corresponding to that interference color from the bottom of the chart.



Determining birefringence

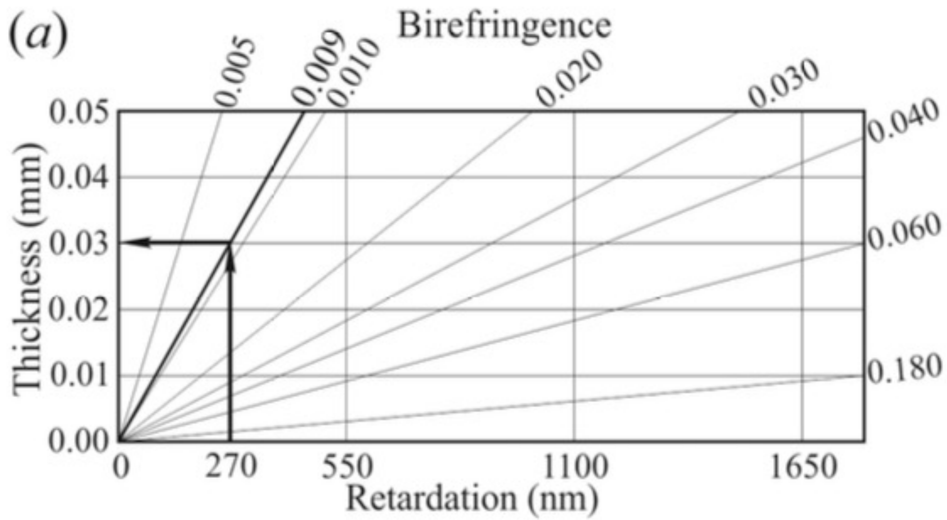
- The maximum birefringence of a mineral is a very useful diagnostic property.
- It is easy to measure in thin sections whose thickness is known.

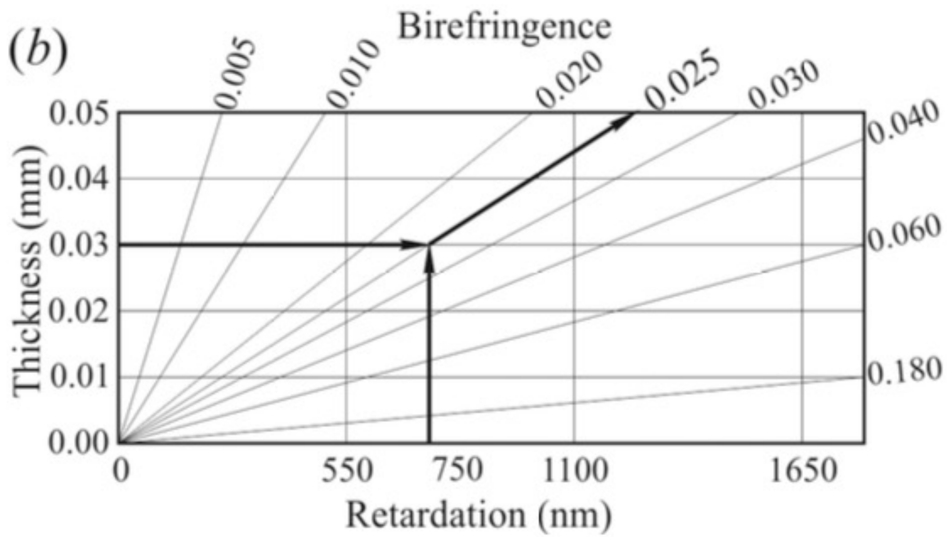
For an unknown mineral:

- For example, the interference color is second-order yellowish green, the retardation is about 750 nm.
- Calculate the birefringence (δ) by using the known thickness of the thin section (e.g., 0.03 mm = 3 × 10^4 nm), and the retardation determined from interference color.

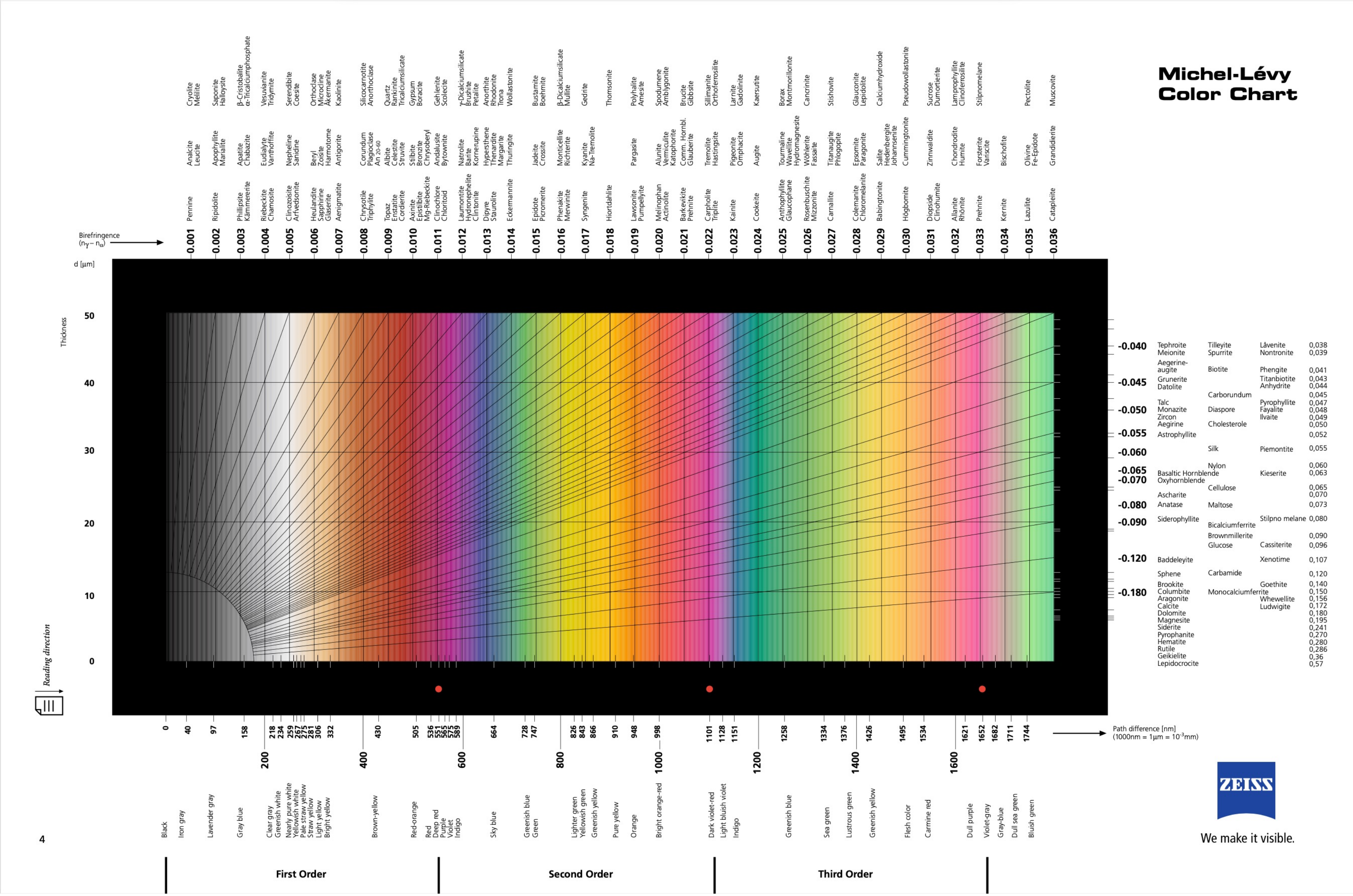
$$\delta = \frac{\Delta}{d} = \frac{750\text{nm}}{3\times10^4\,\text{nm}} = 0.025$$

- Check the chart to look for possible minerals





Michel-Levy Color Chart



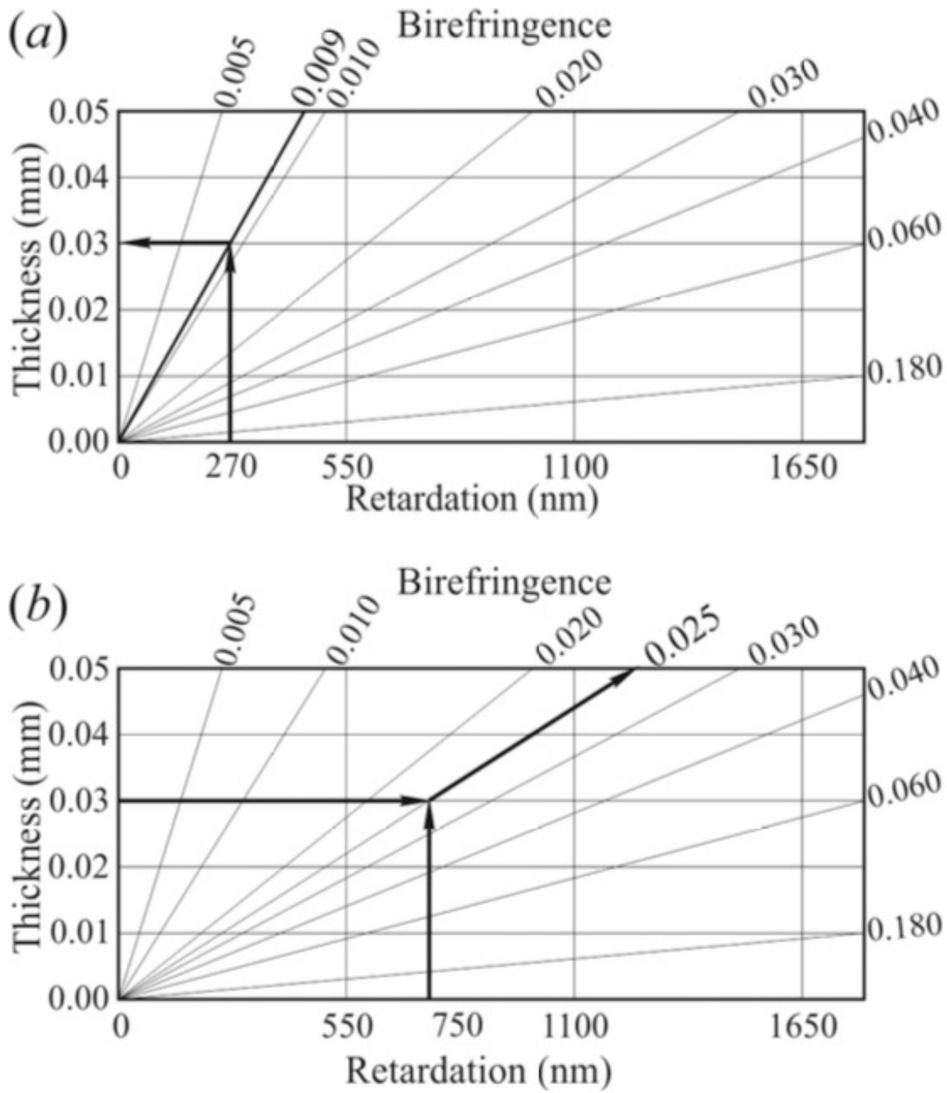
Determining birefringence

Sources of error

- Thickness of the thin section.
- The inability to accurately recognize interference colors of minerals
- Inaccurate color recognition or interpretation of the interference color chart.
- None of the grains in the sample may be cut along the right orientation so that the birefringence is the maximum value.

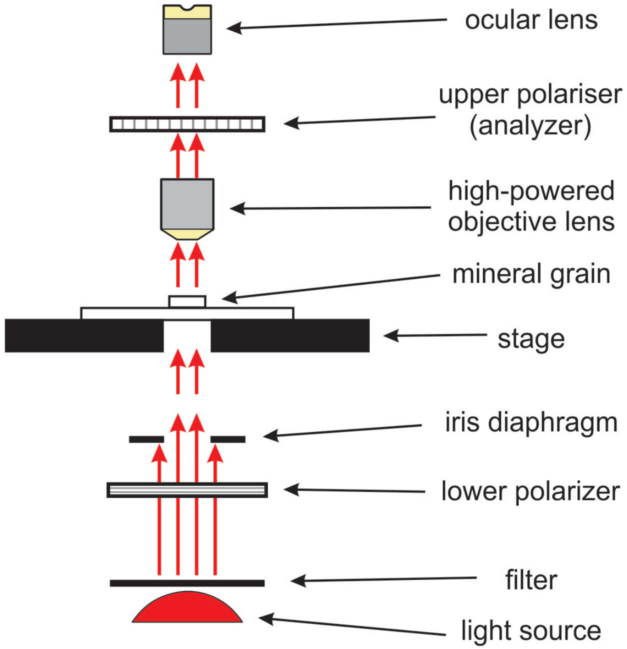
✓ Regardless of these limitations, the method provides sufficient accuracy for routine mineral identification work with the petrographic microscope.

✓ Recognition of unknown mineral should be aided by other optical properties as well. ***E.g. habit of the grain, color in PPL, pleochroism, cleavages and extinction angles.***

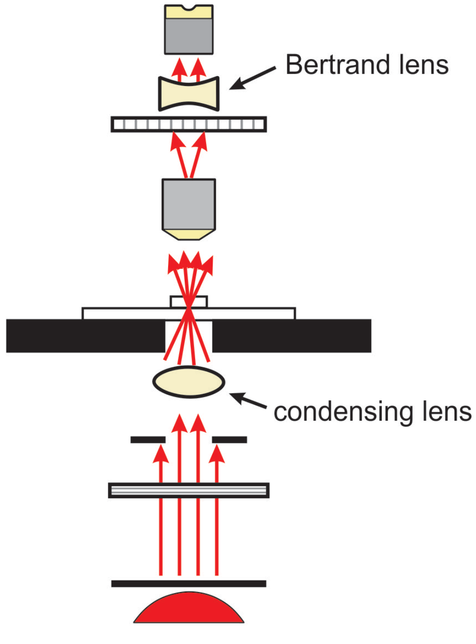


Thank

You



standard
orthoscopic
illumination



conoscopic
illumination