Optical Mineralogy

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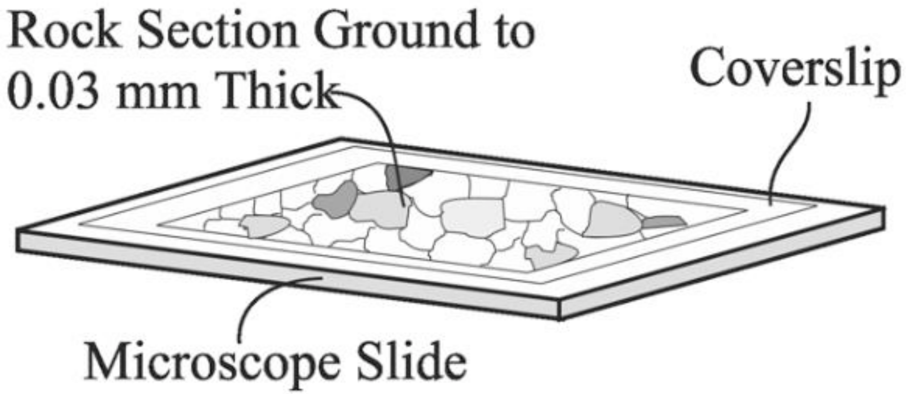
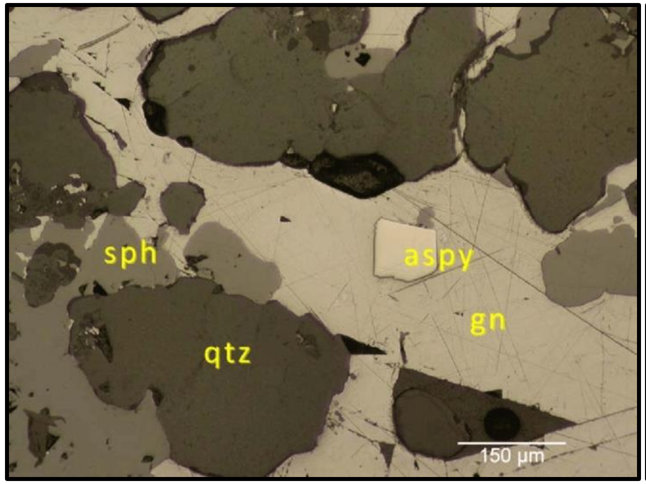
Introduction

❑ What is optical Mineralogy?

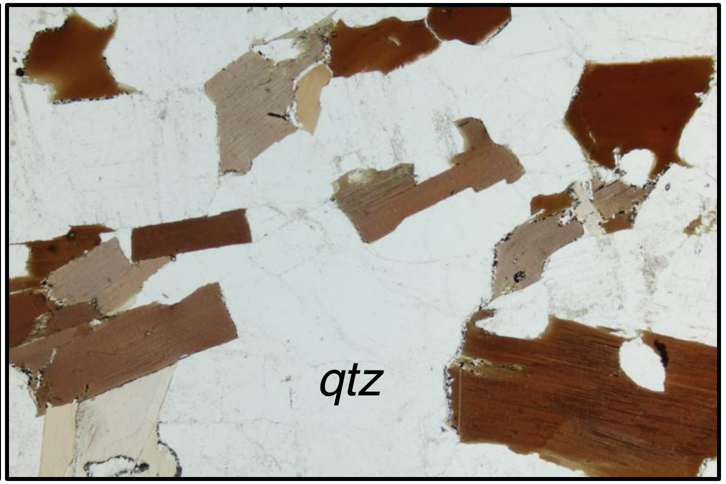
Analysing thin slices of minerals or rocks under transmitted or reflected light.

- **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.**

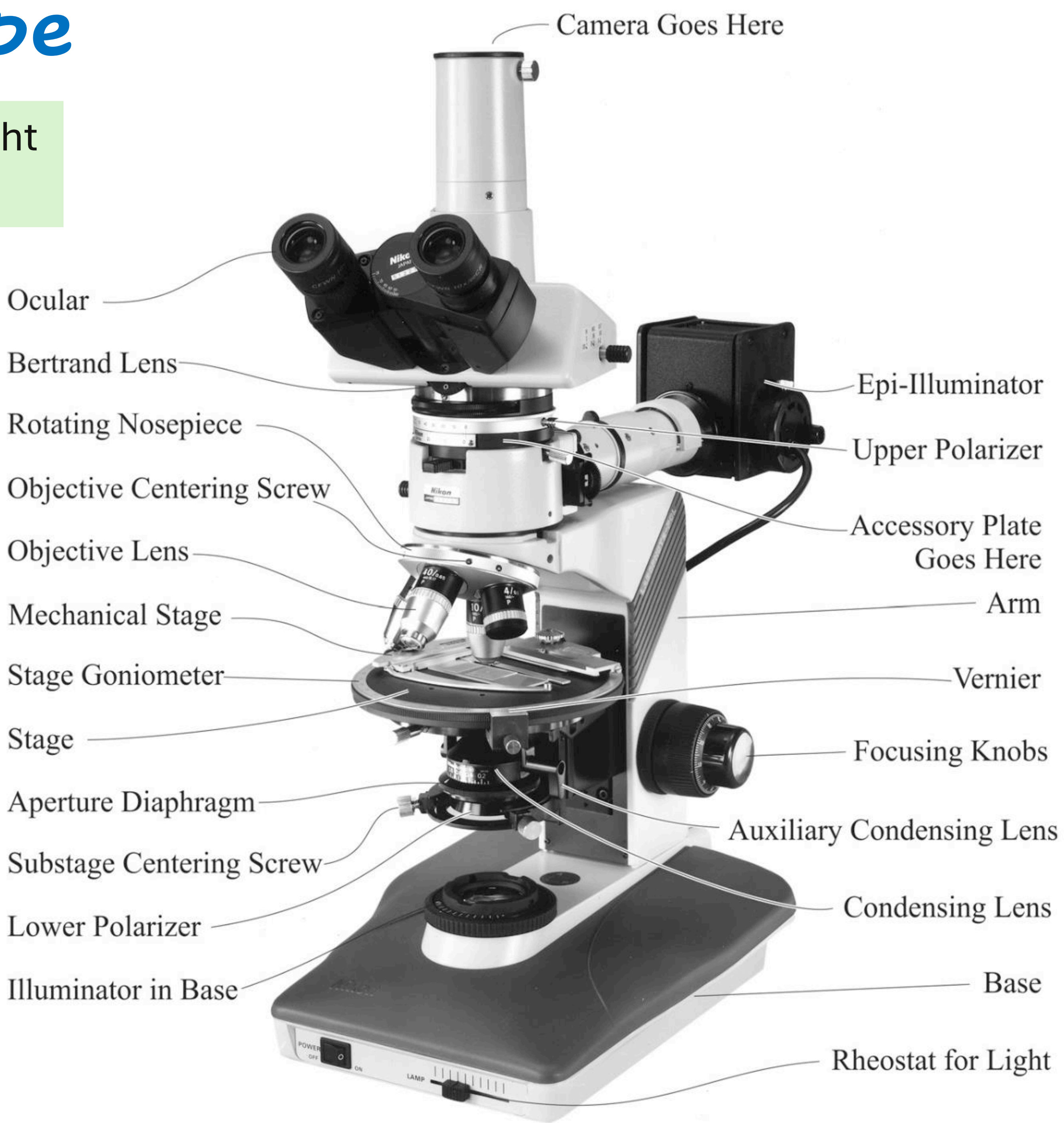
Petrographic microscope provides one of the primary means of studying minerals and the rocks they comprise.

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

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

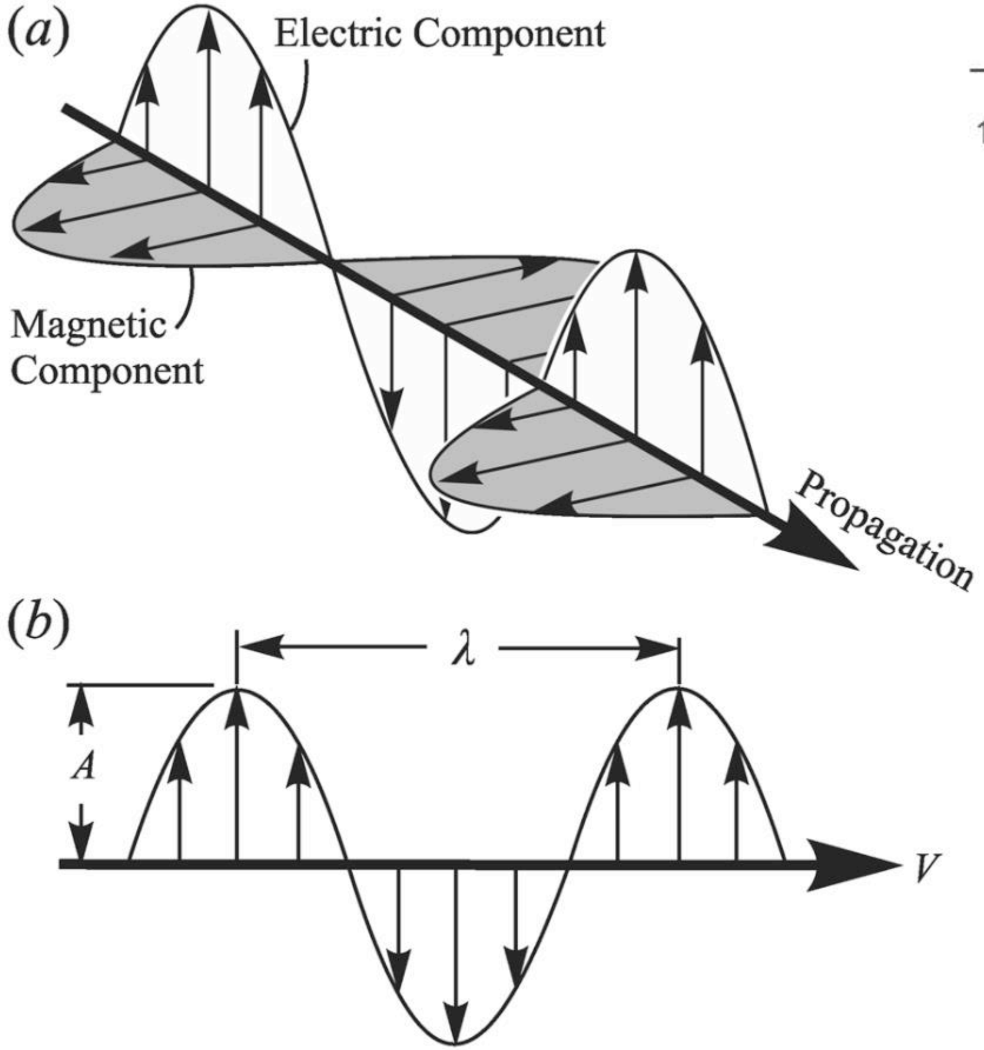
✓ Microscopic properties which cannot be observed in a hand specimen

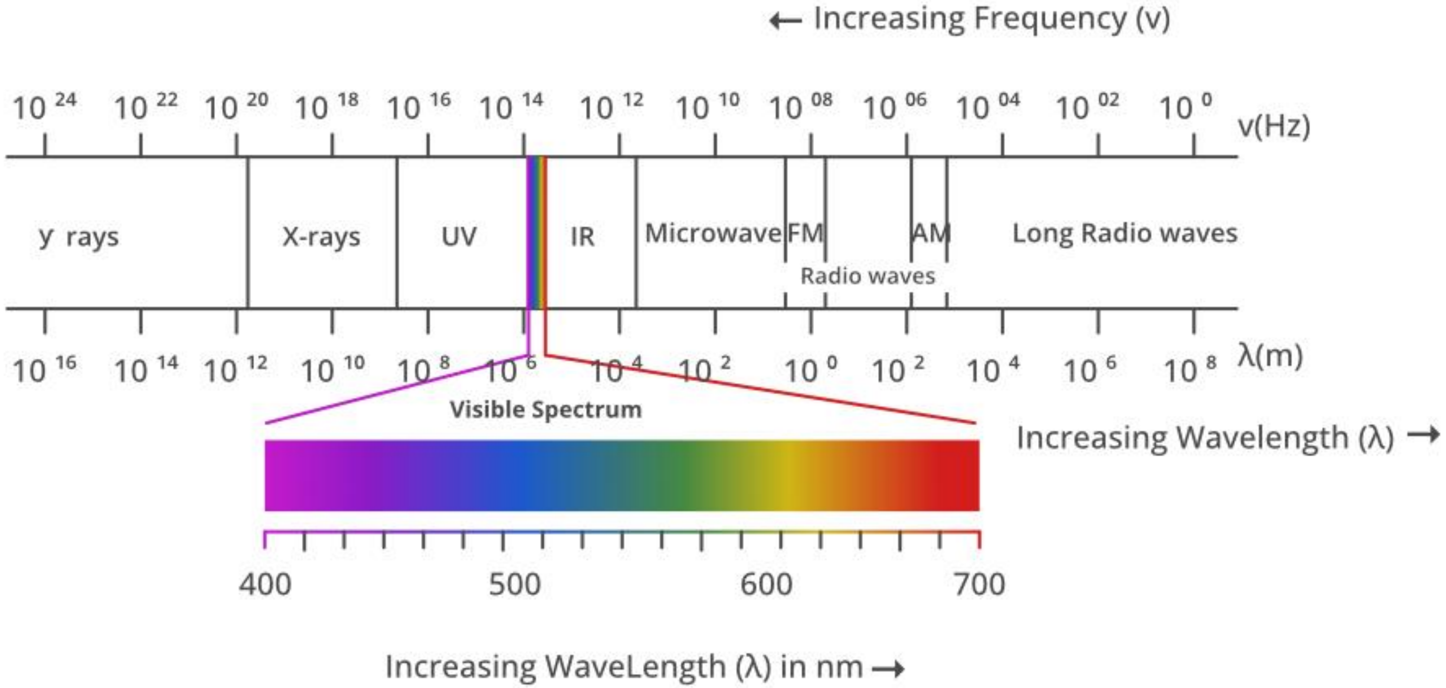
✓ Relation between the different mineral grains



Basics of optics

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





$V = f\lambda$

V : *velocity (m/s)*

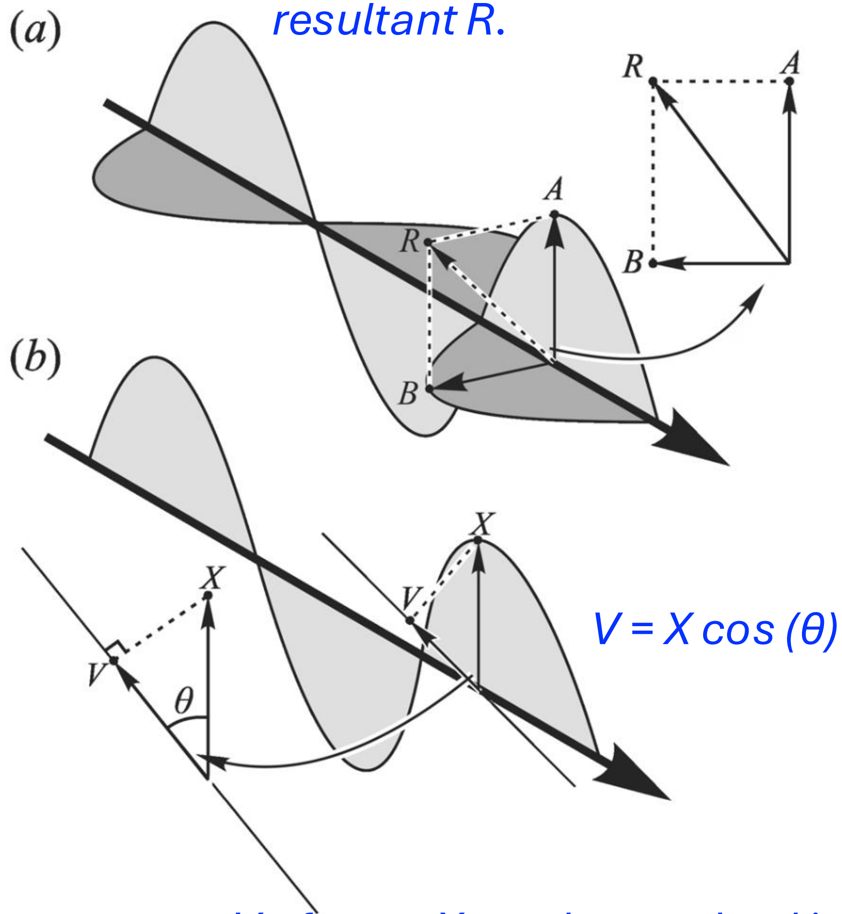
f : *frequency (cycles/s)*

λ : *wavelength (m)*

Basics of optics

Vector resolution of light waves.

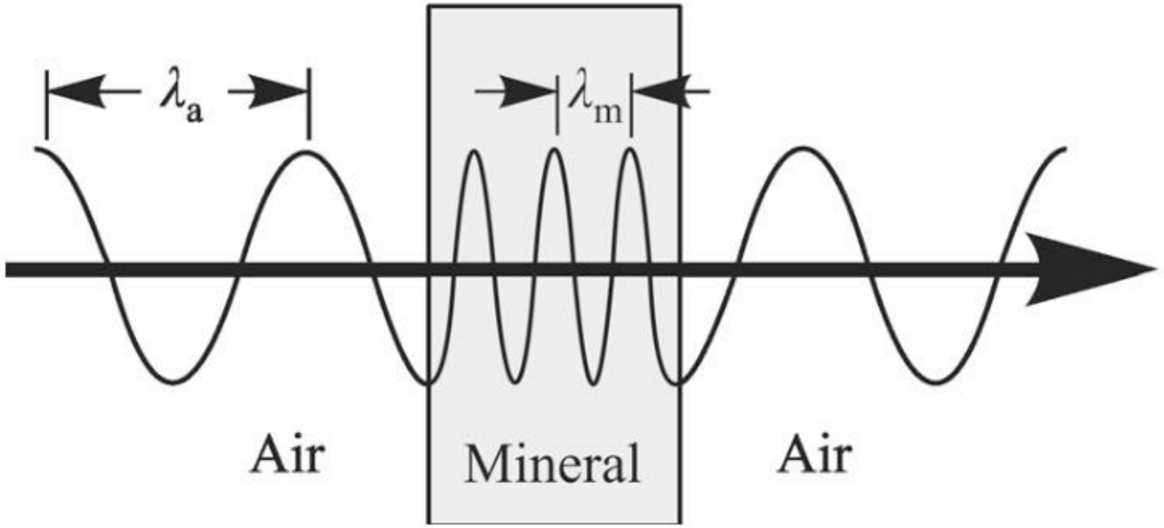
Waves A and B form resultant R.



$V = X \cos(\theta)$

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

Interaction of light with mineral



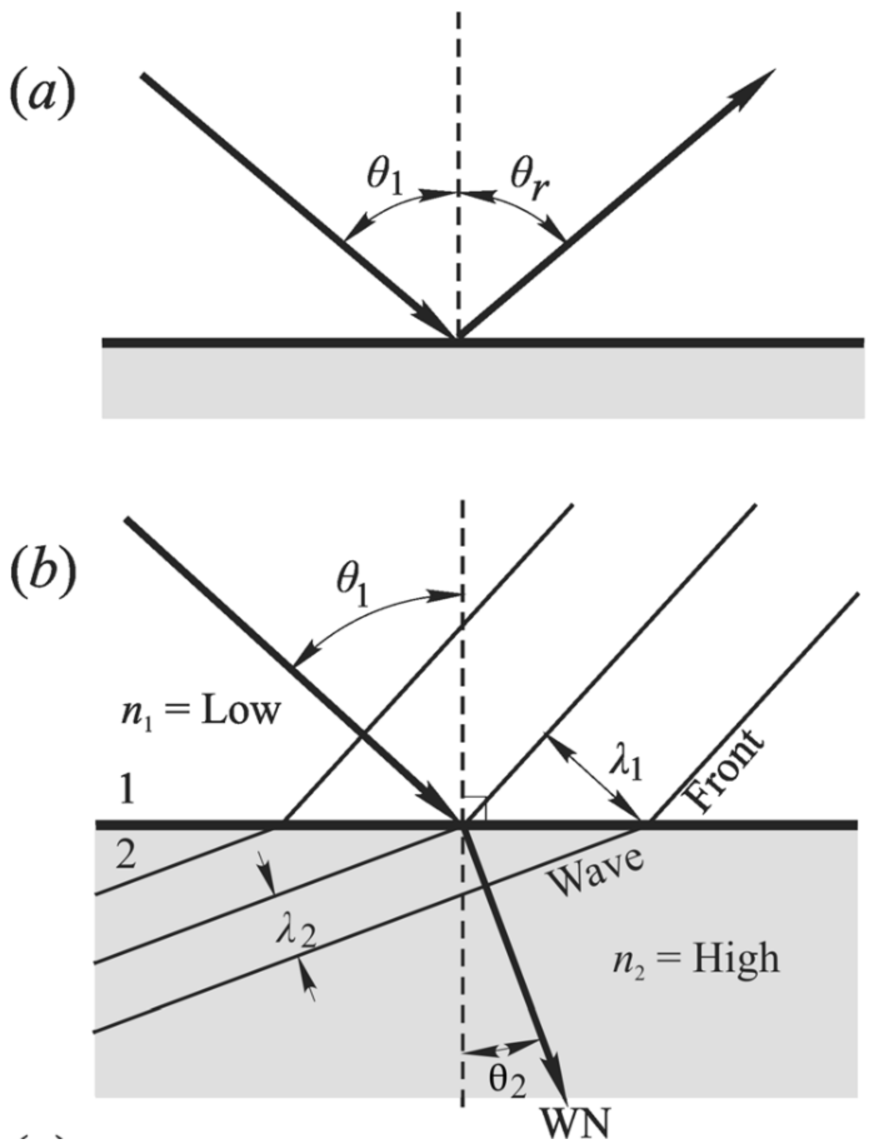
- ✓ *Light slows down and wavelength decreases*
- ✓ *Frequency remains the same*

Refractive index

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

Basics of optics

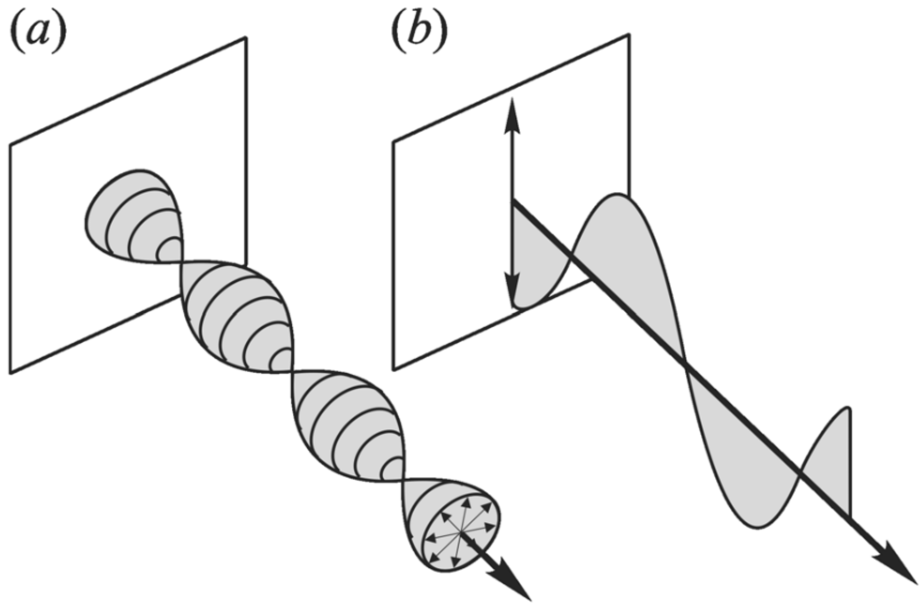
Reflection and refraction



Snell's Law

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

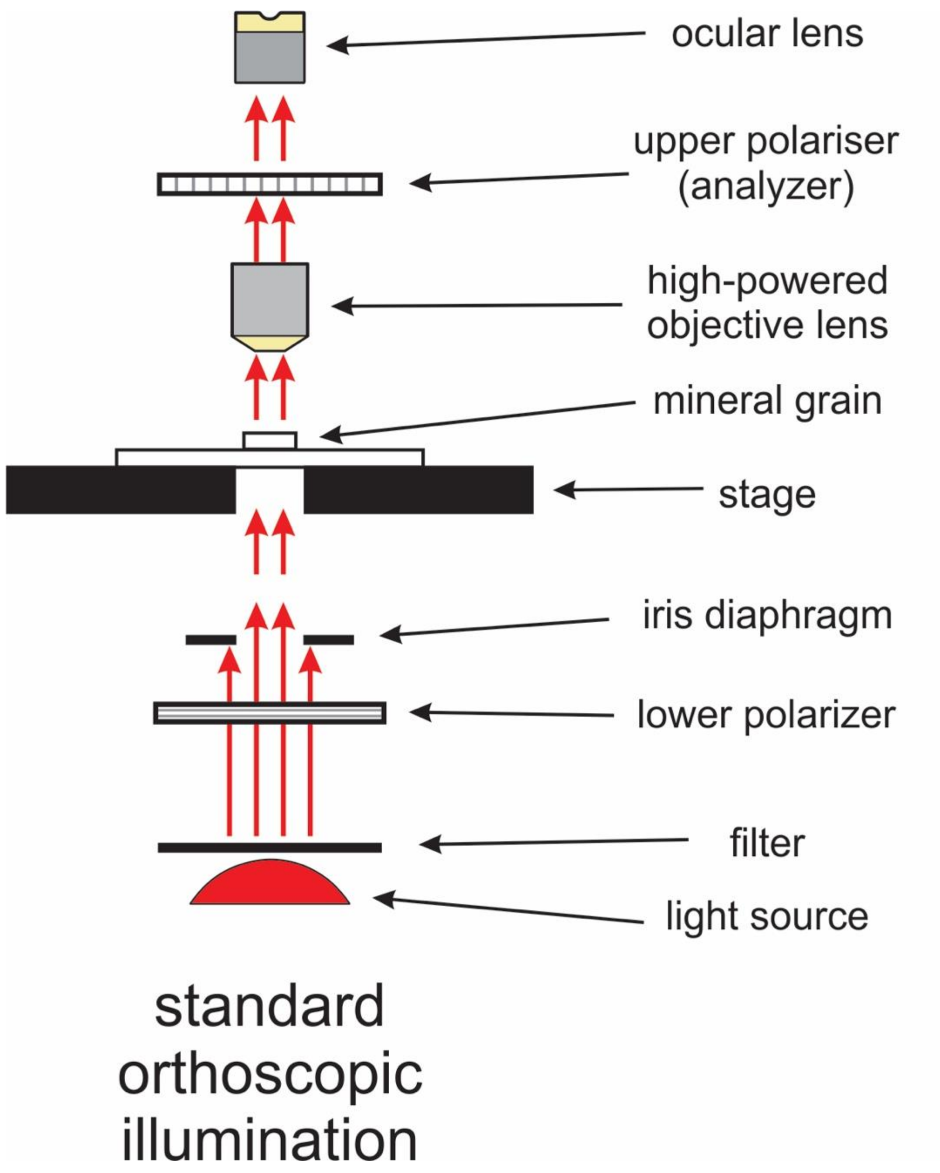
Polarized light

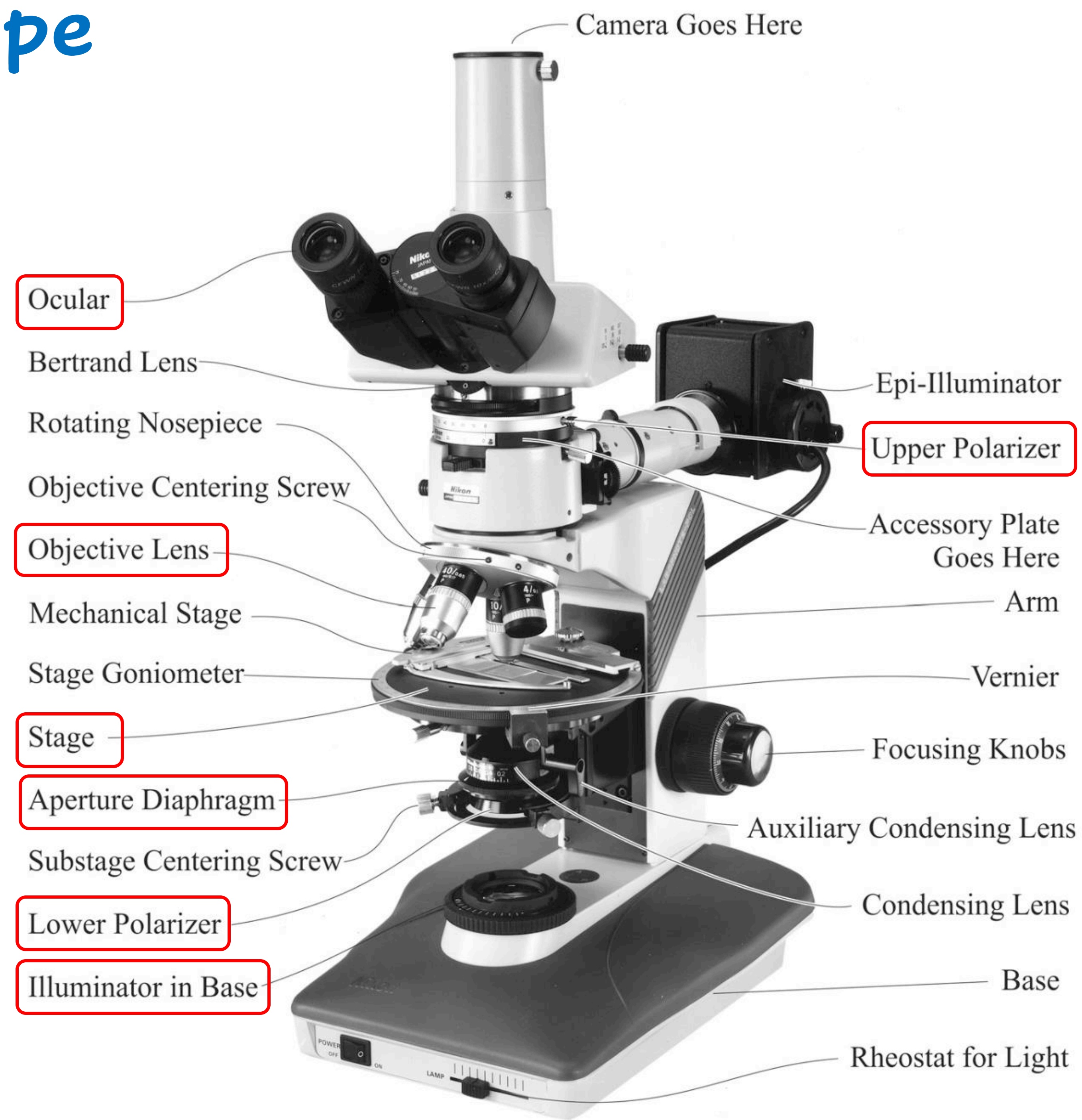


- ✓ Ordinary light coming directly vibrates in all directions at right angles to the direction of propagation – **Unpolarized light.**
- ✓ If the vibration of the light is constrained to lie in a single plane – **Plane polarized.**
- ✓ Vibration can be represented by a simple **sine wave.**

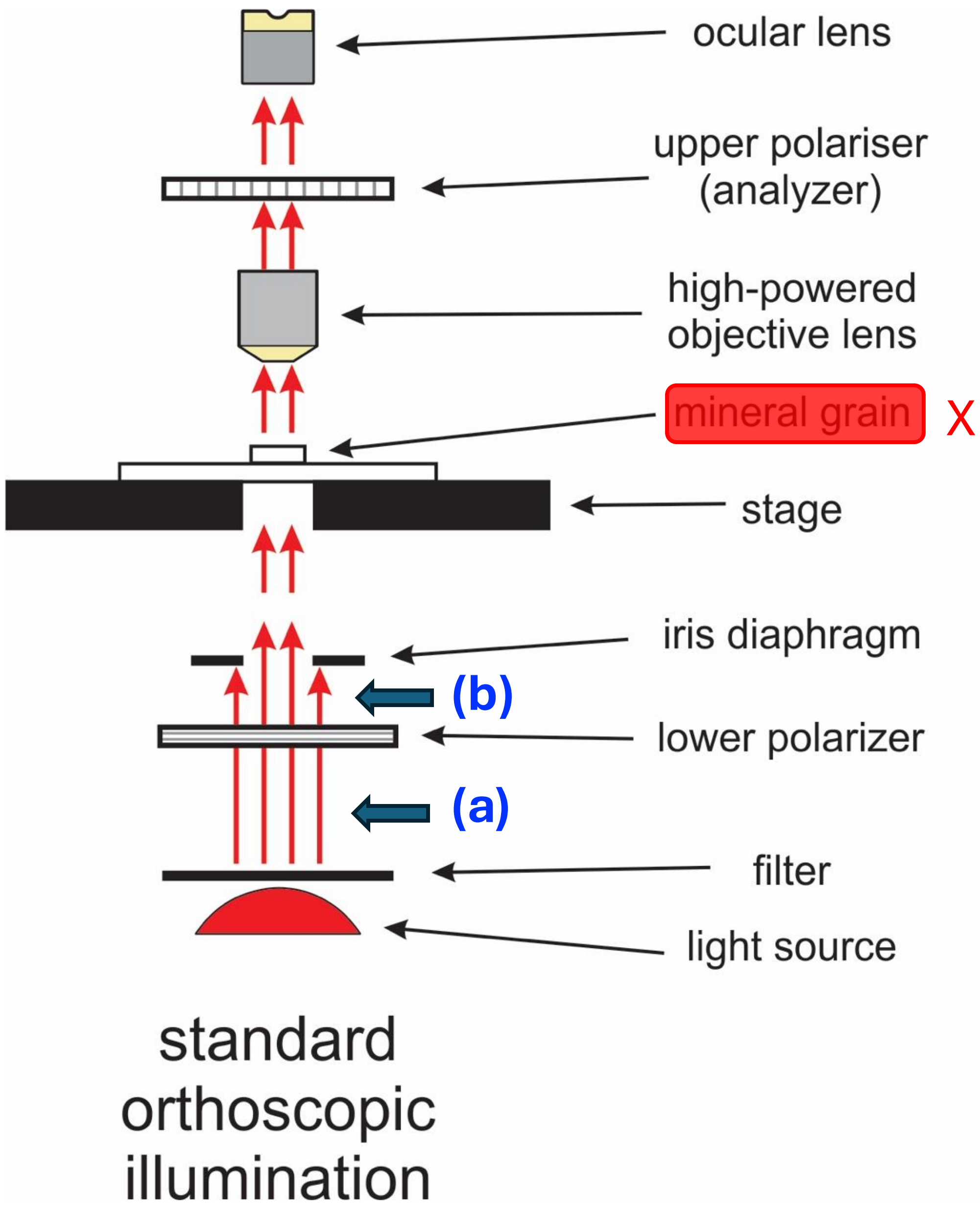
Petrographic Microscope

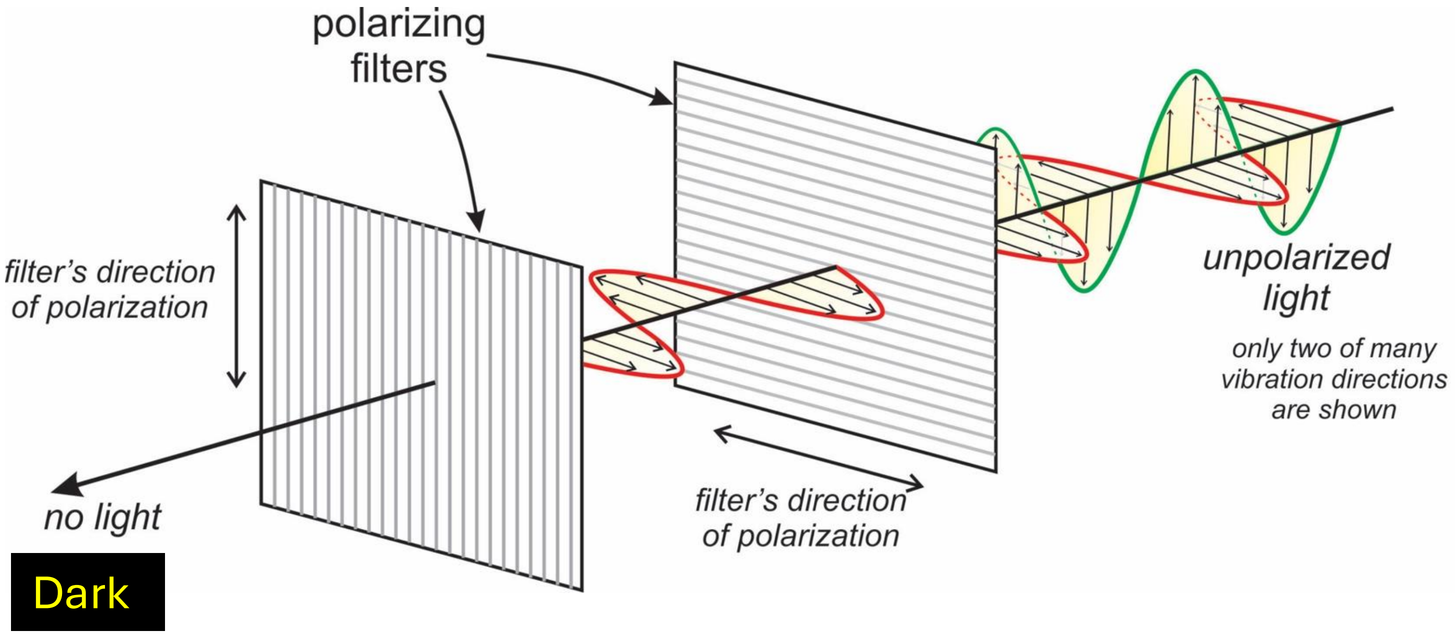
Fundamentals of a petrographic microscope

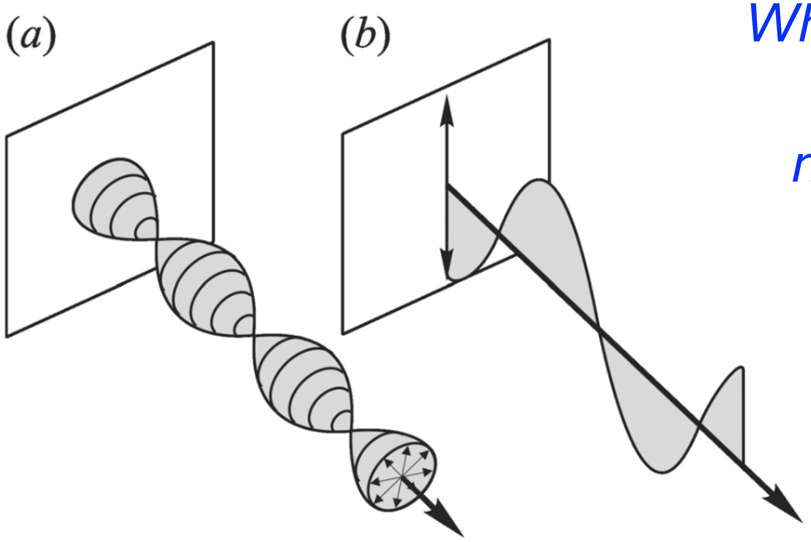




Petrographic Microscope

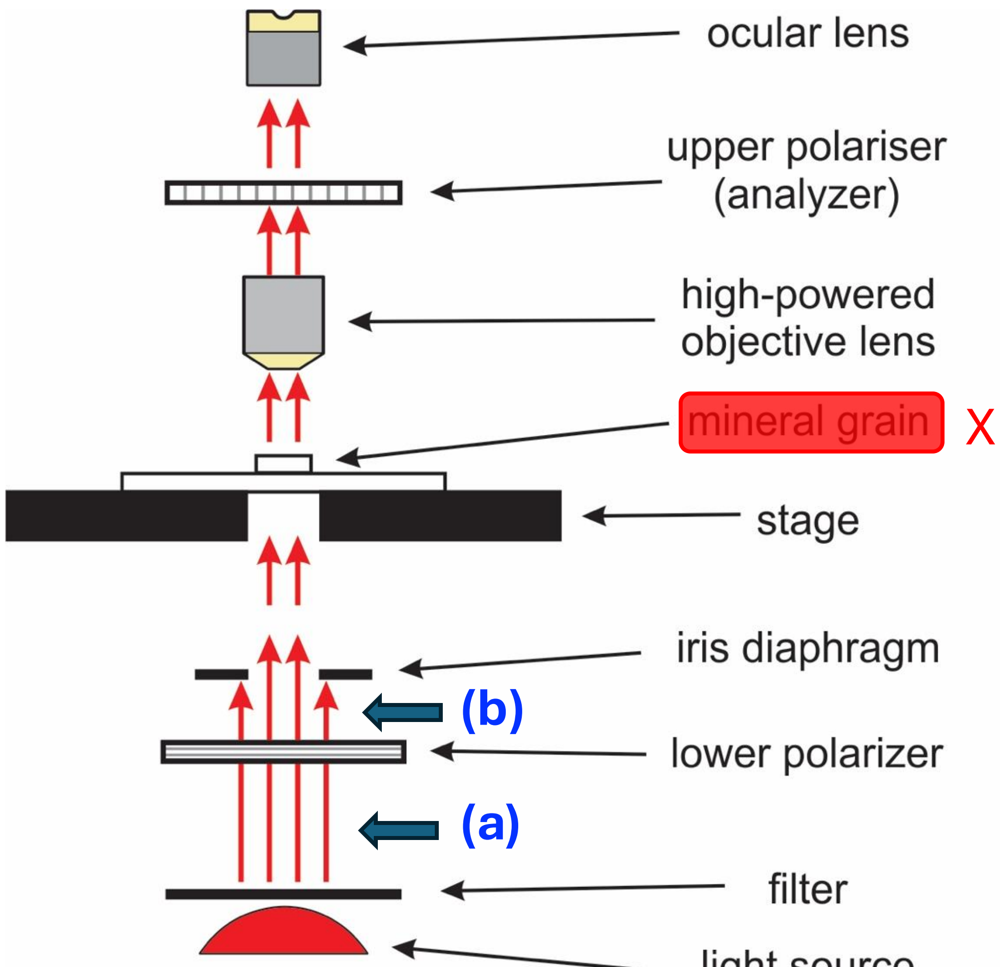






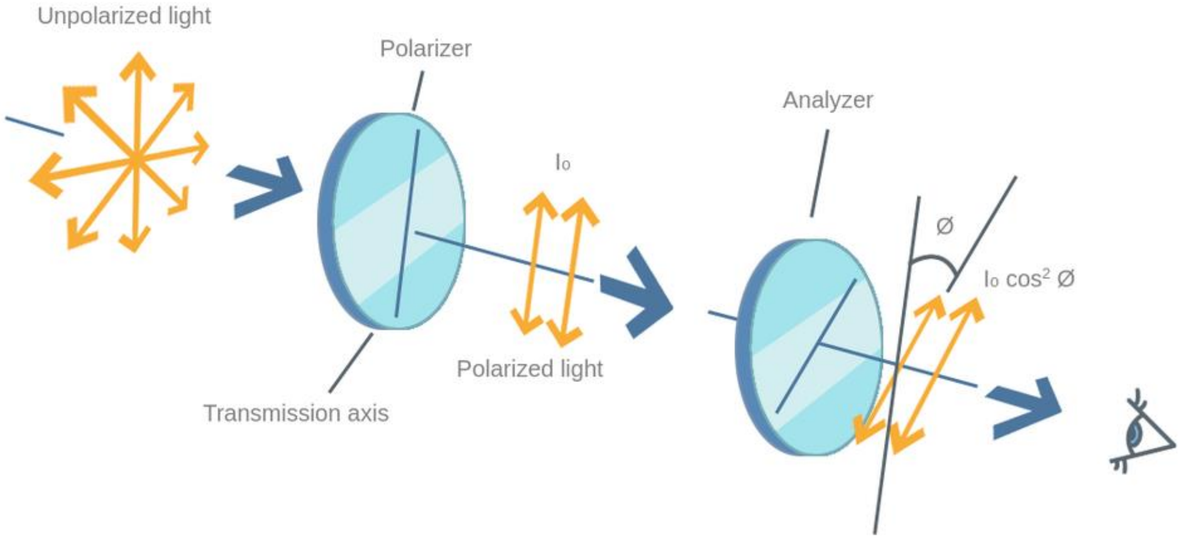
What happens when light passes through a microscope without a mineral grain?

Petrographic Microscope

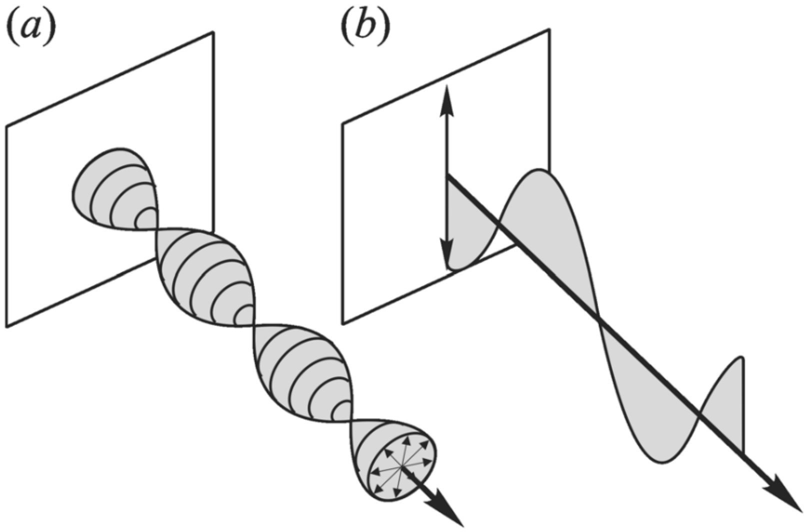


standard
orthoscopic
illumination

What happens if the two polarizers are not perpendicular?



If θ becomes 90°?



Isotropic and anisotropic mineral

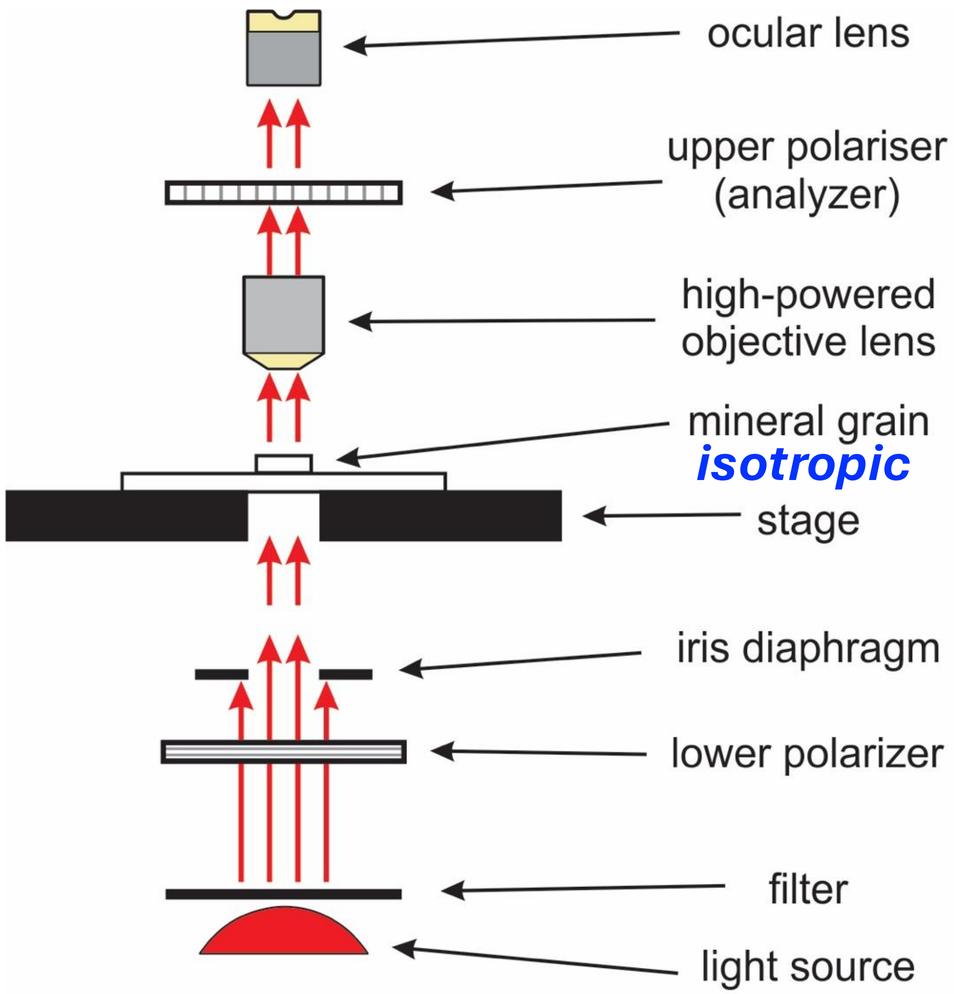
❑ Isotropic mineral

- 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.

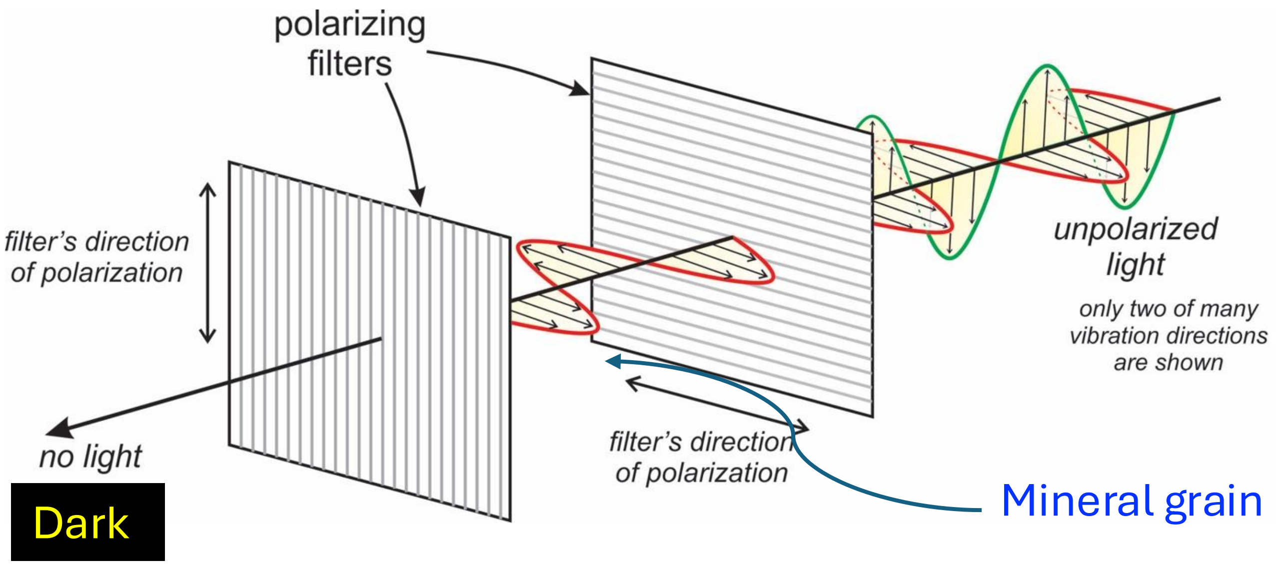
❑ Anisotropic mineral

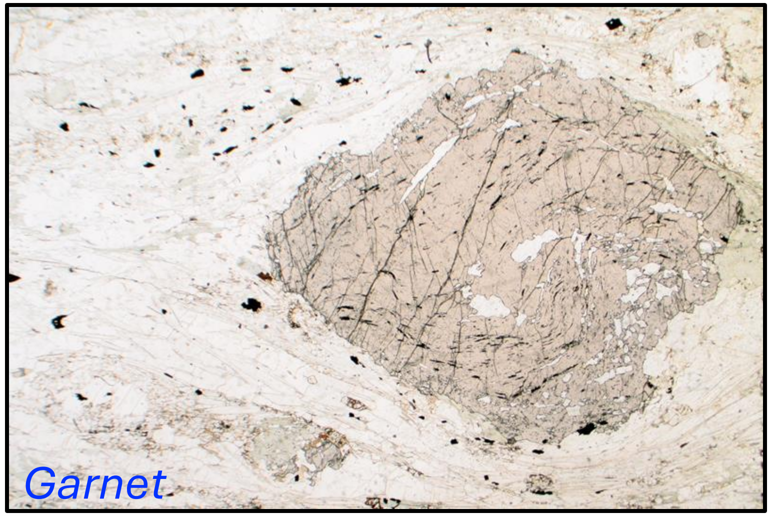
- An **optically anisotropic** material is one in which the velocity of light is different in different directions.
- The electron density varies with direction.
- The electrons of the atoms/ions in these minerals are not able to interact with light in the same way in all directions.
- The velocity and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

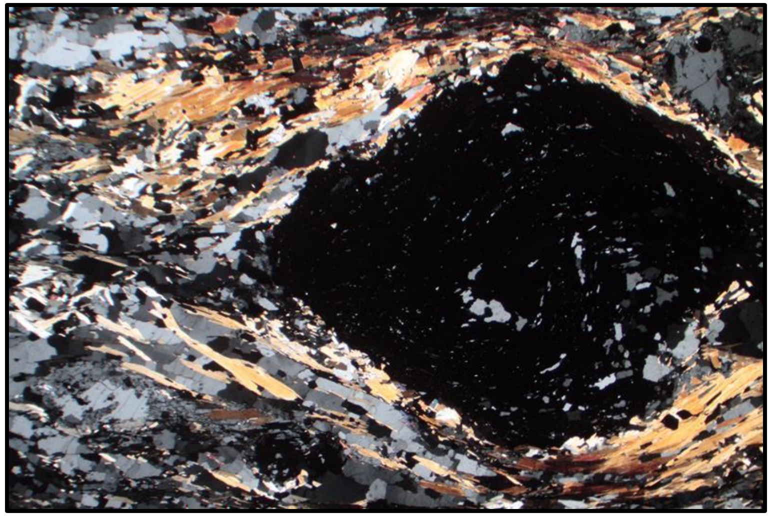
Isotropic mineral



standard orthoscopic illumination





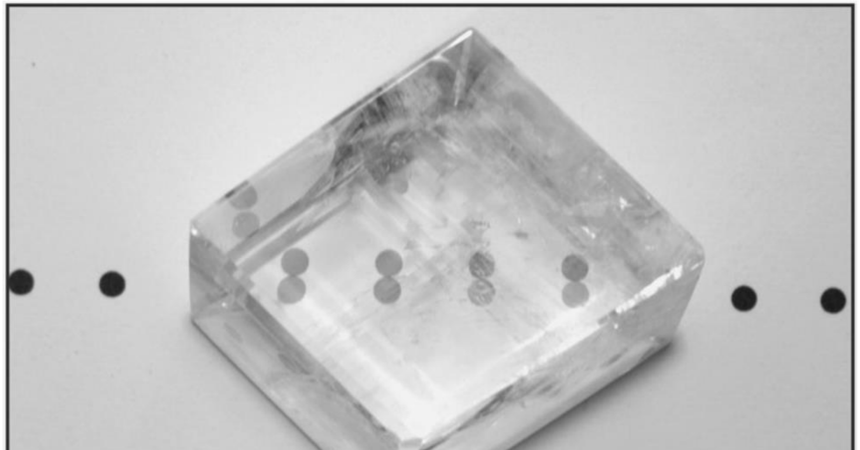


Plane Polarized Light (PPL)

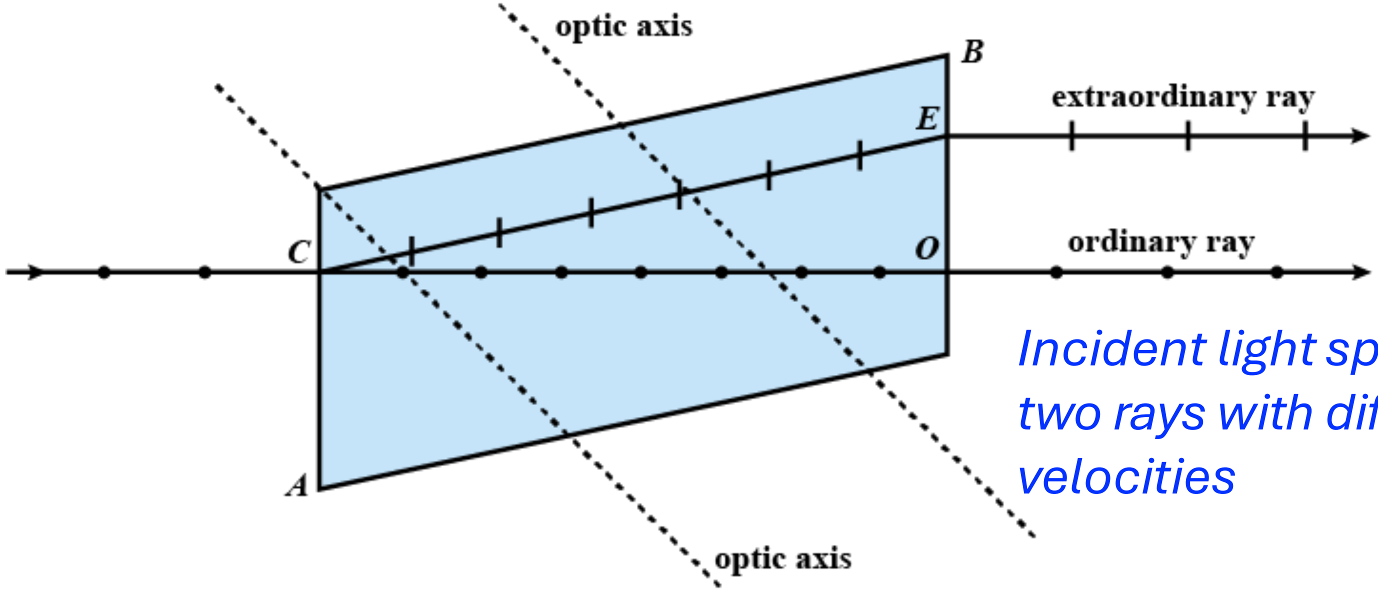
Crossed Polarized Light (XPL)

Light through an anisotropic mineral

Anisotropic minerals show double refraction



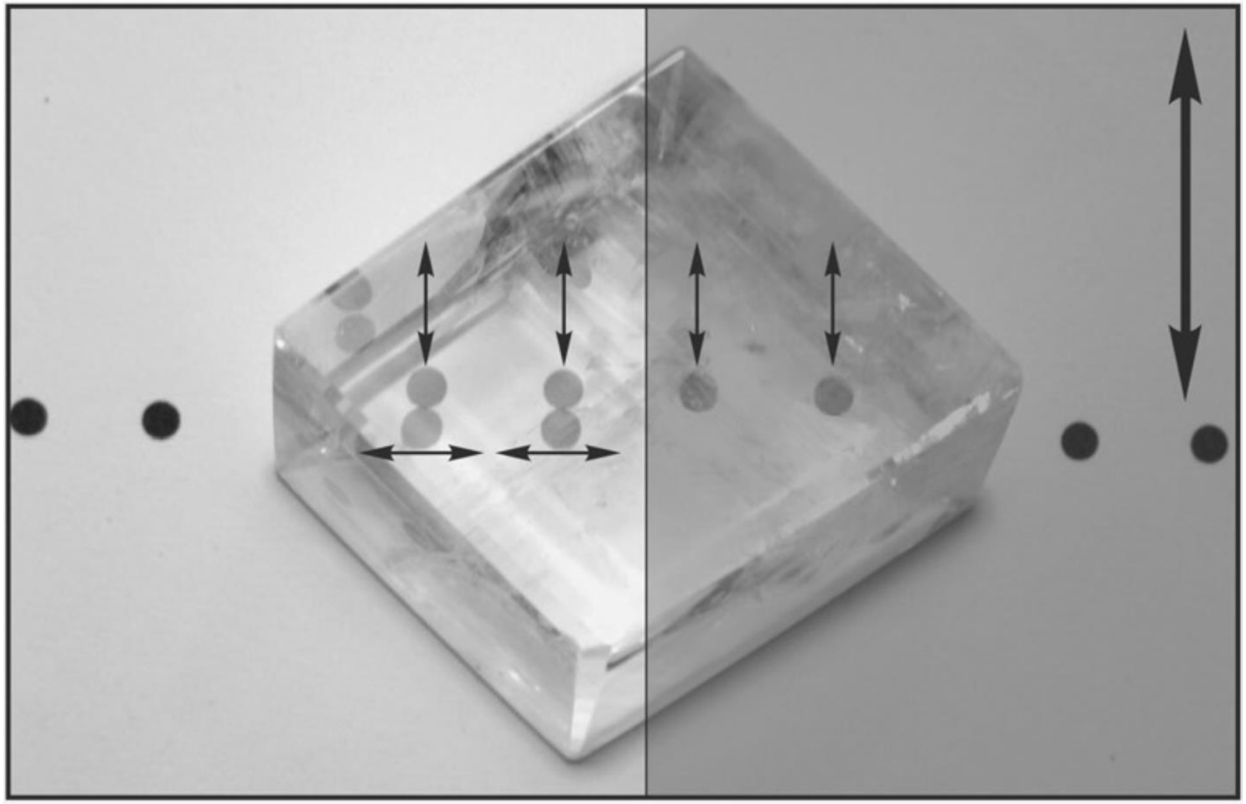
Two images corresponding to the two rays are produced

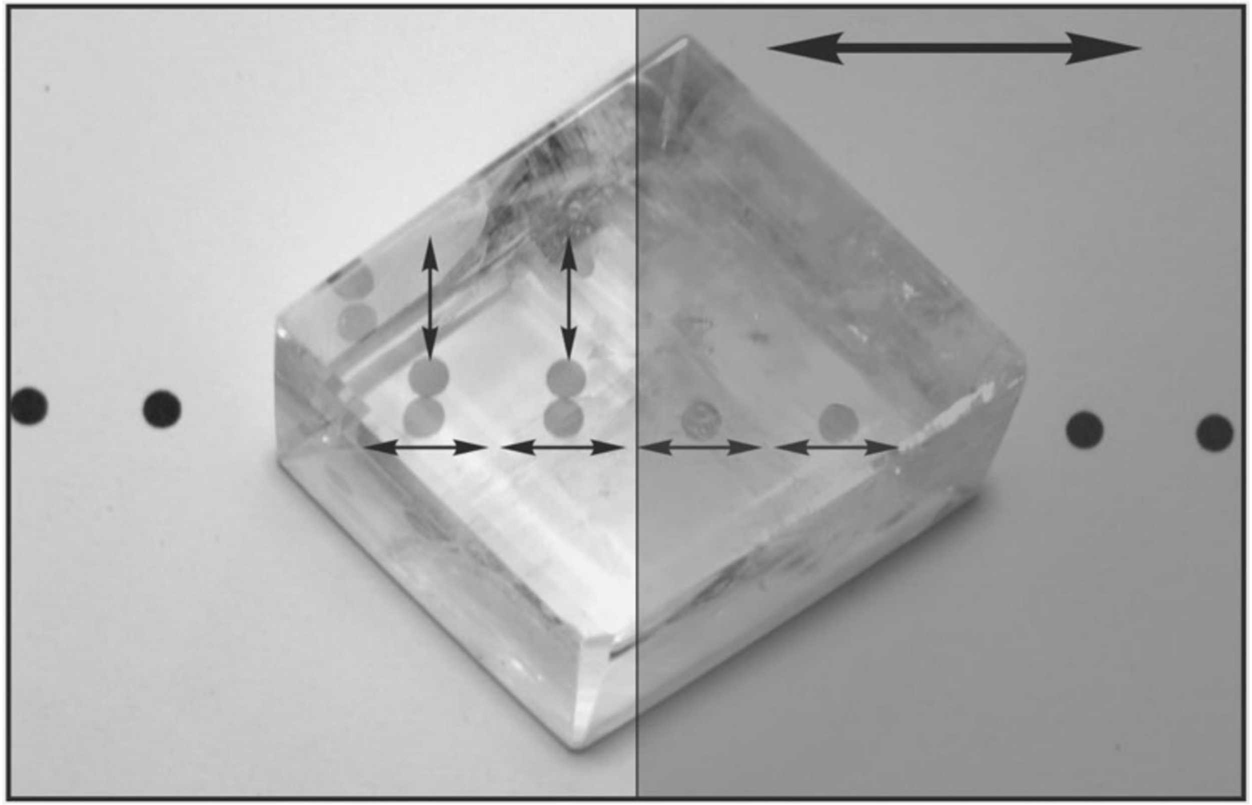


Incident light splits into two rays with different velocities

- ***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



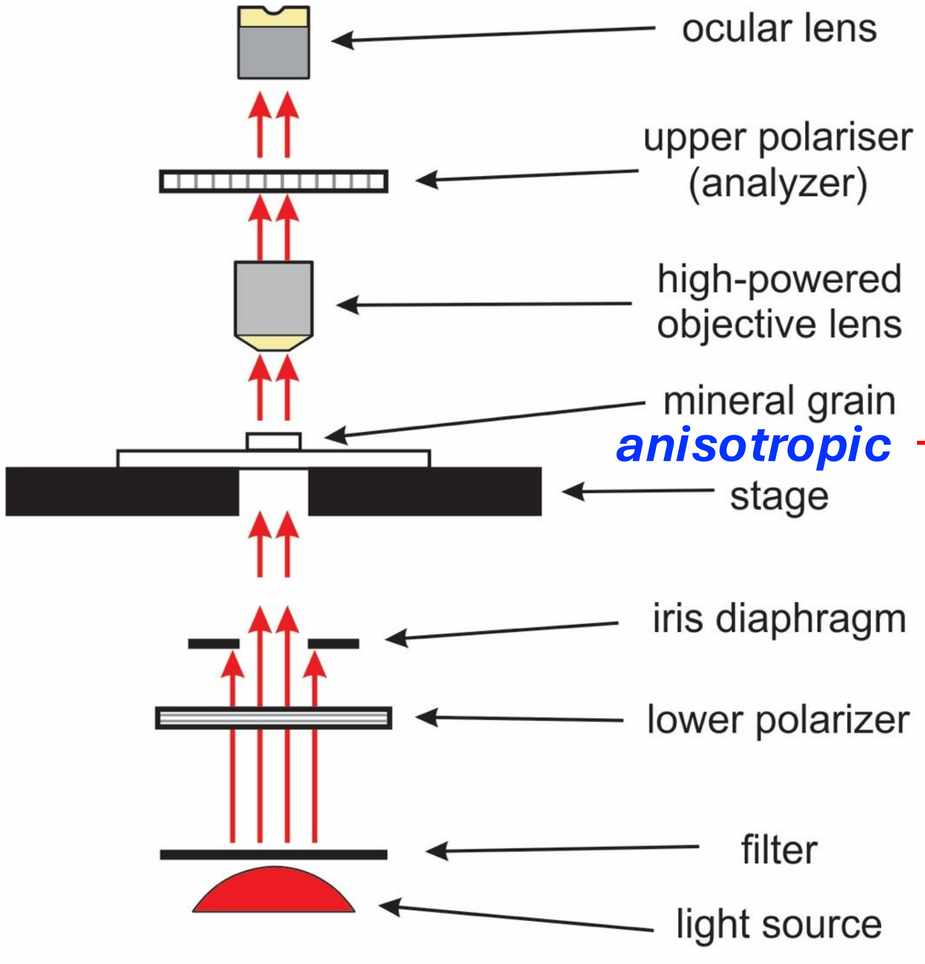


- A polarizing film whose vibration direction is parallel to the short diagonal of the rhomb passes one set of dots and absorbs the other.

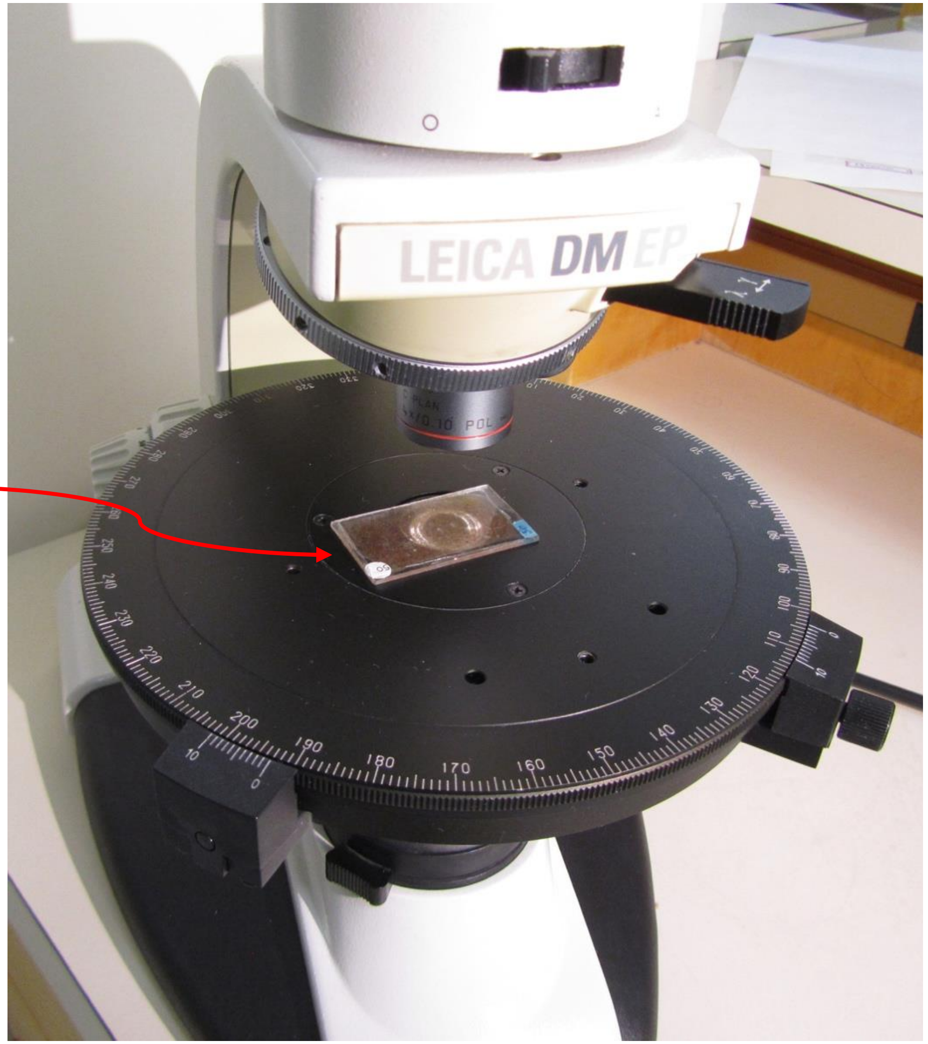
- The polarizing film is rotated 90°.
- The first set of dots is absorbed and the other passes.
- In intermediate orientations, both sets of dots are visible with subdued brightness.

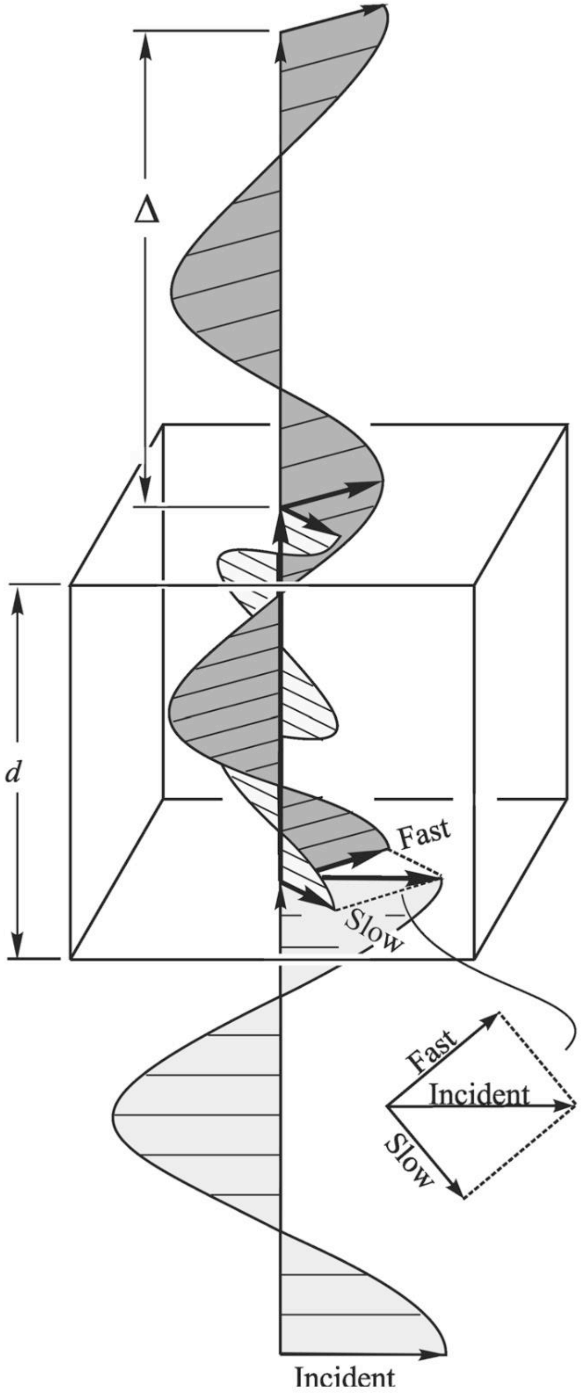
The two rays must therefore be plane polarized and vibrating at right angles to each other.

Double refraction



anisotropic



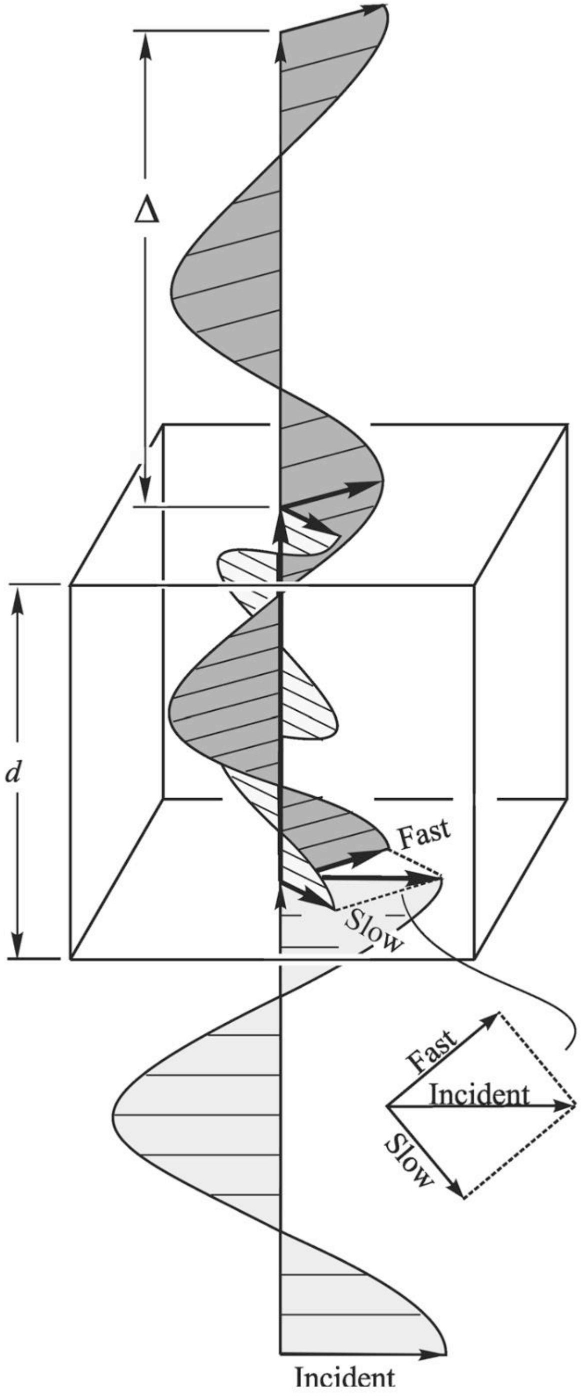


Double refraction

- 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.

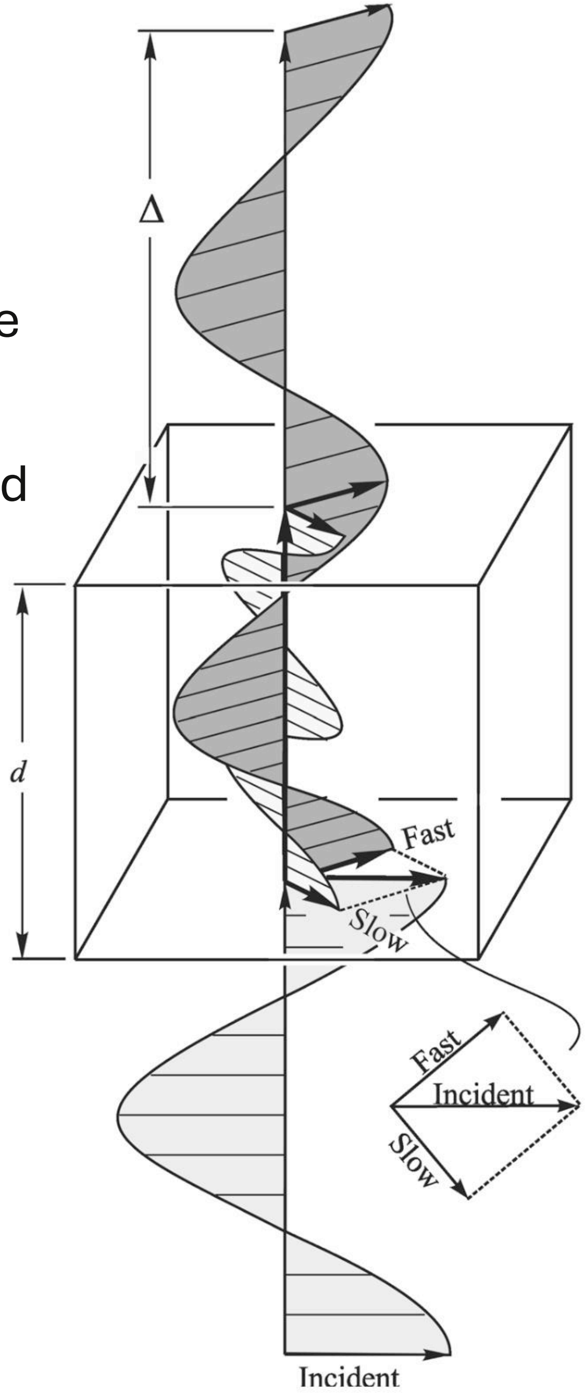


Double refraction

- 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

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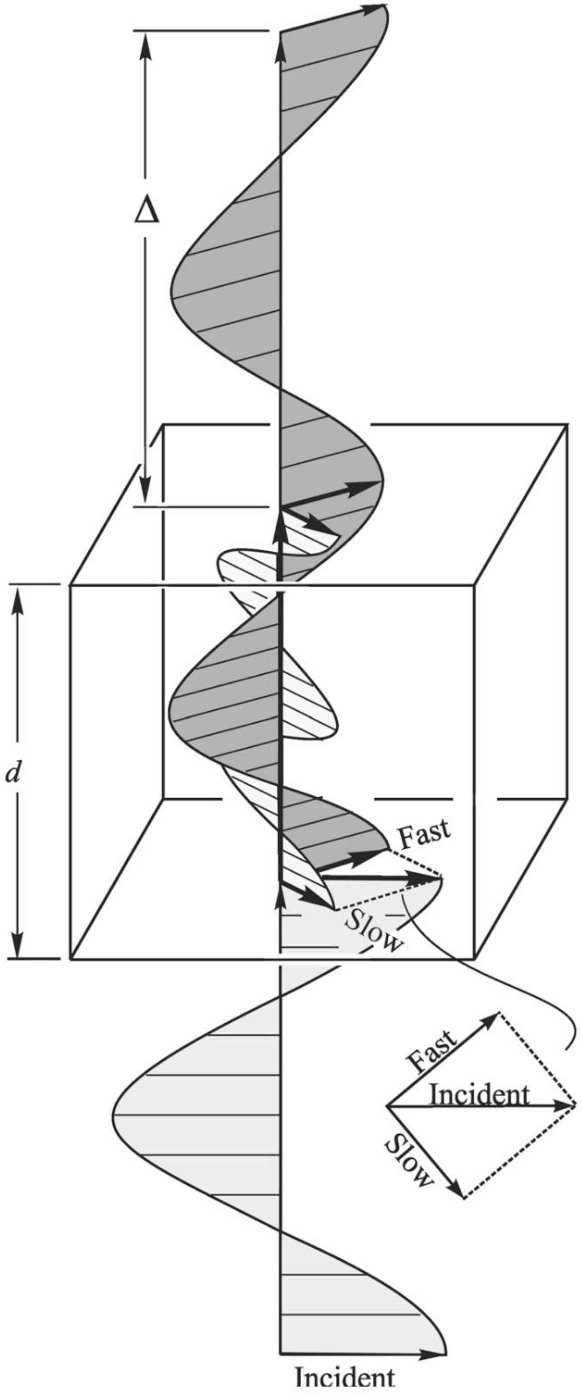
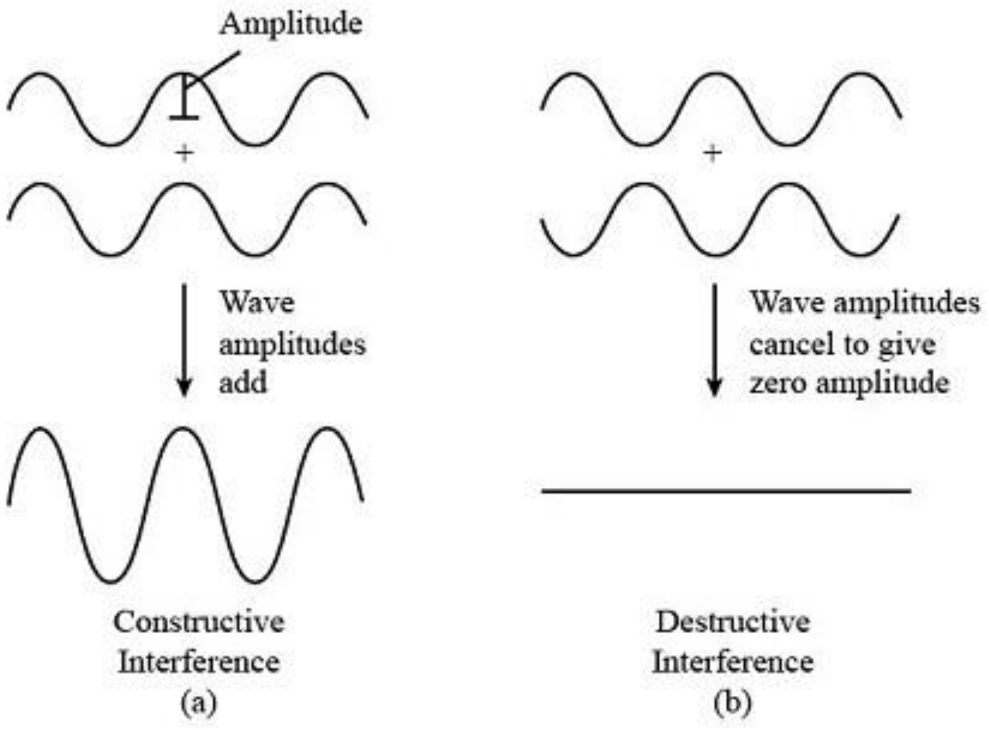
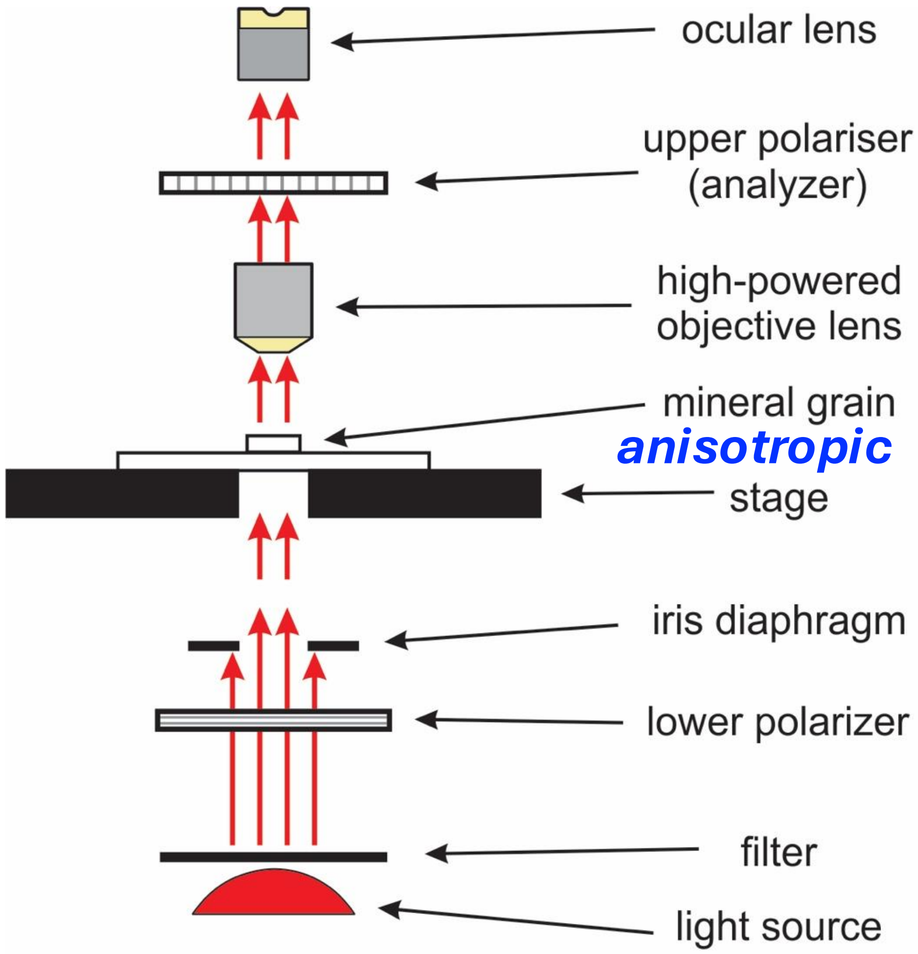
$$t = \frac{d}{v_s} = \frac{d}{v_f} + \frac{\Delta}{V_0} \Rightarrow \Delta = d\left(\frac{V_0}{v_s} - \frac{V_0}{v_f}\right),$$

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



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

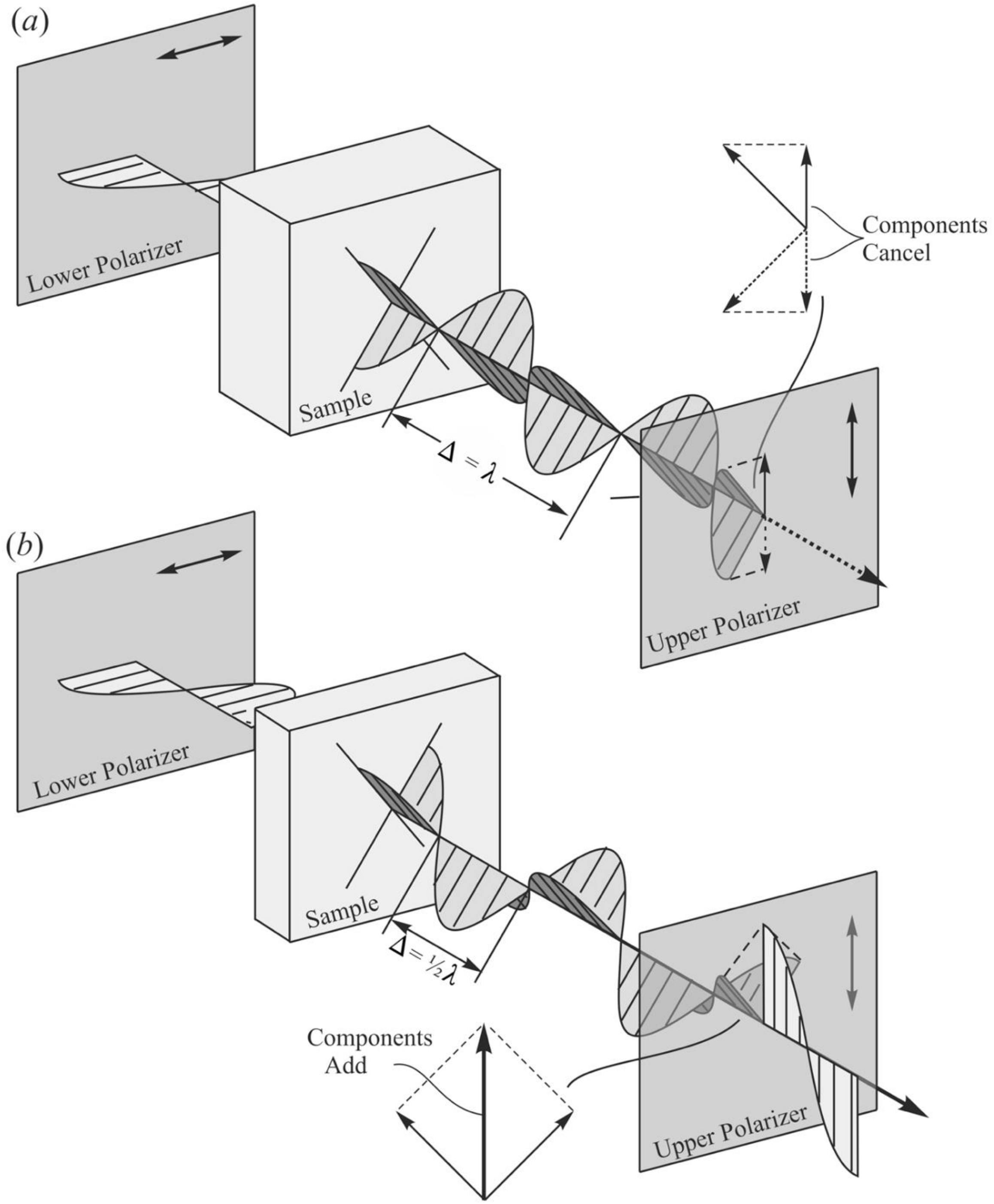
$$\Delta = i\lambda$$ *i : integer; λ : wavelength*

- 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*