Chapter 3: Optics of Anisotropic minerals

SARAH LAMBART

Recap chapter 2

- Refractometry
  - ⇔ determination of the refractive index
  - 3 methods:
    - Oil immersion
    - Becke Line
    - Oblique illumination (lab)
  - Physical concept:
    - Lens effect
    - Double refraction effect

Content Chapter 3 (1½ lecture)

- **Optics of anisotropic minerals**
  - **Interference phenomena**
  - **Birefringence color**
  - **Accessory plates**
  - **Extinction**
  - **Sign of elongation**

ANISOTROPIC MINERALS

- **Isotropic mineral:** velocity of light is the same in all the directions. n = constant – mineral in the isometric (= cubic) system. (Ex. Diamond)
- **Anisotropic minerals:** velocity of light is **not** the same in all the directions + BIREFRINGENCE

ANISOTROPIC MINERALS

- **Isotropic mineral:** velocity of light is the same in all the directions. n = constant – mineral in the isometric (= cubic) system. (Ex. Diamond)
- **Anisotropic minerals:** velocity of light is **not** the same in all the directions + BIREFRINGENCE
  - **Uniaxial:** <u>tetragonal and hexagonal</u> crystal systems: 2 extreme (or end-member) values of refractive indices (Ex. Quartz, Calcite)
  - **Biaxial:** <u>triclinic, monoclinic, orthorhombic</u> systems: 3 refractive indices. (Ex. Feldspars, pyroxenes, amphiboles)

INTERFERENCE PHENOMENA

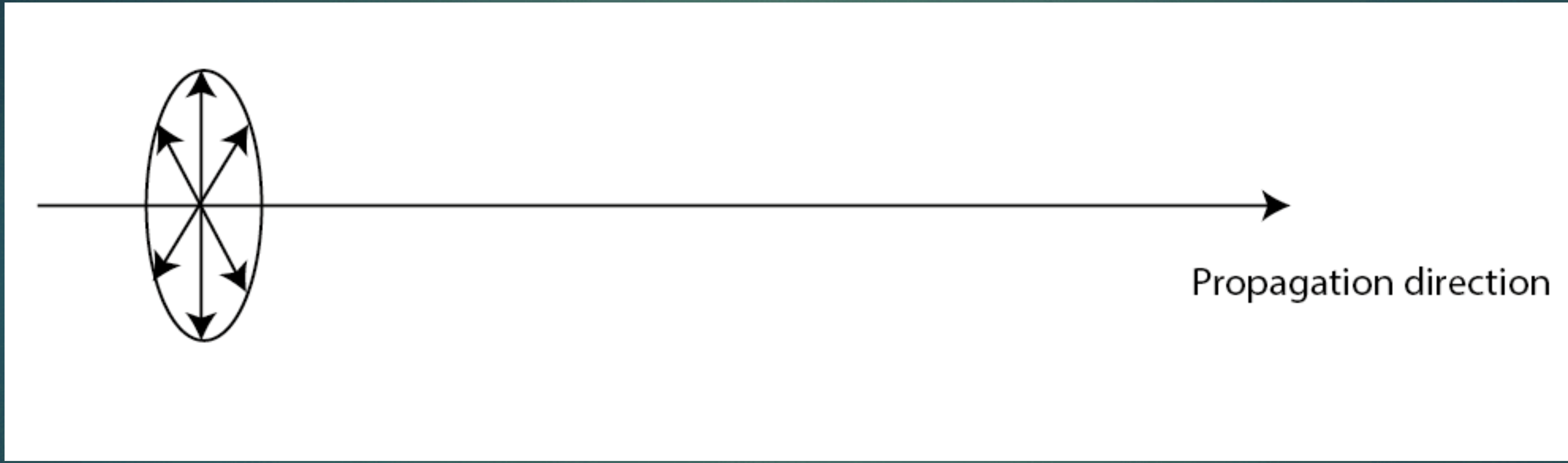
- **Birefringence (or double refraction):**

⇒ 2 rays with 2 different angles ⇔ 2 indices of refraction

- **Notation:**
  - Refracted ray with the highest n (smallest angle), is the slow ray
  - Refracted ray with the lowest n (smallest angle), is the fast ray

INTERFERENCE PHENOMENA

- **Propagation direction vs. vibration direction**



INTERFERENCE PHENOMENA

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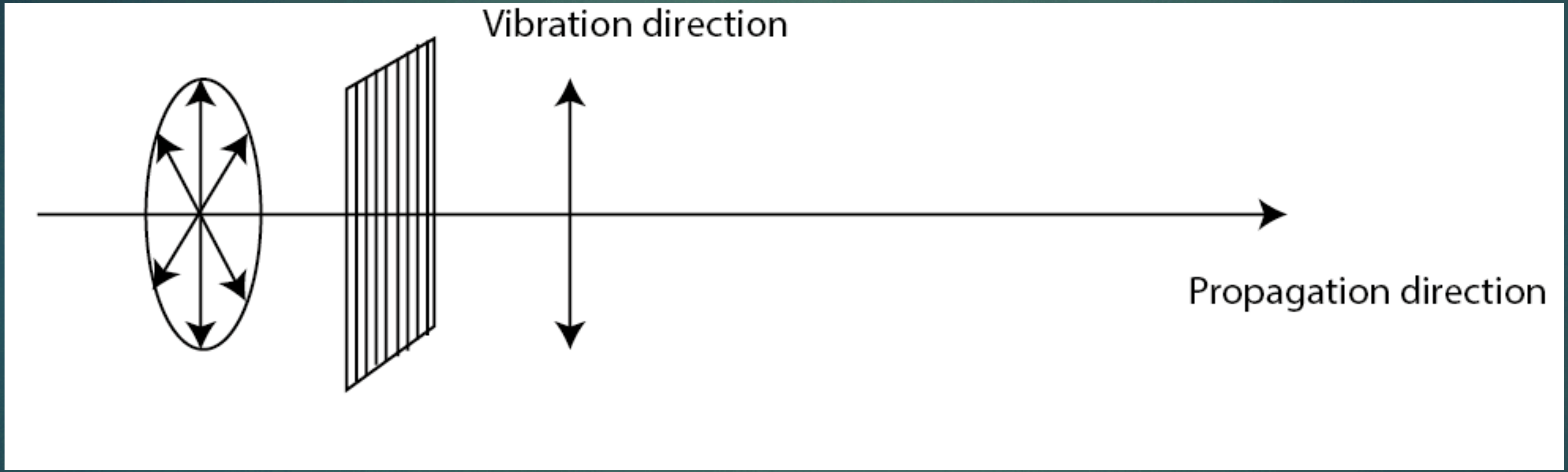

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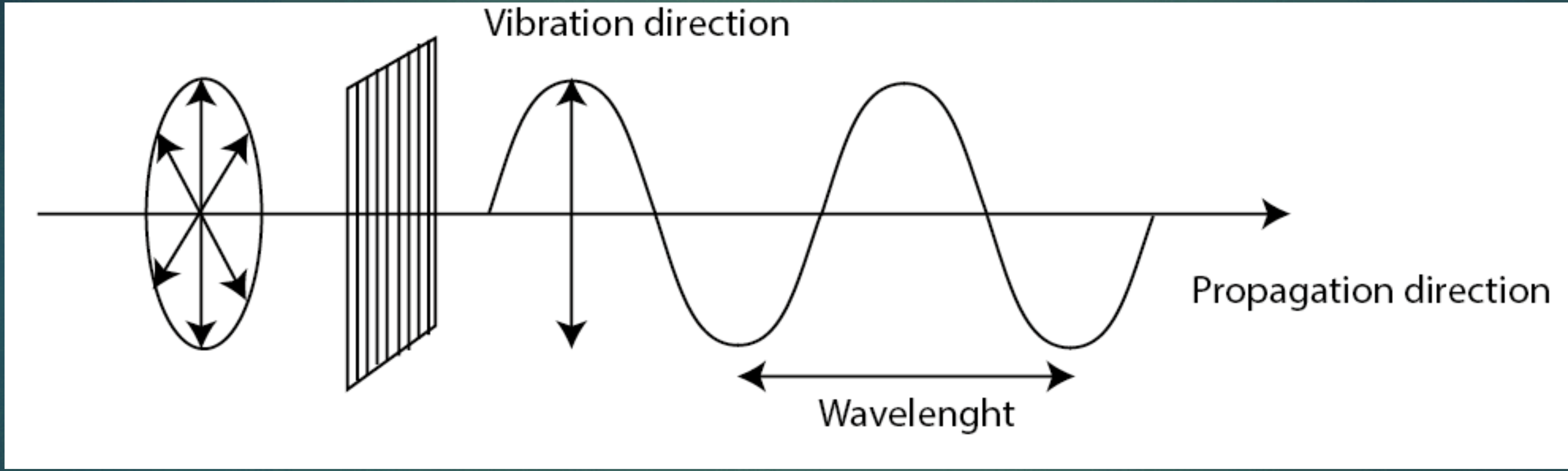

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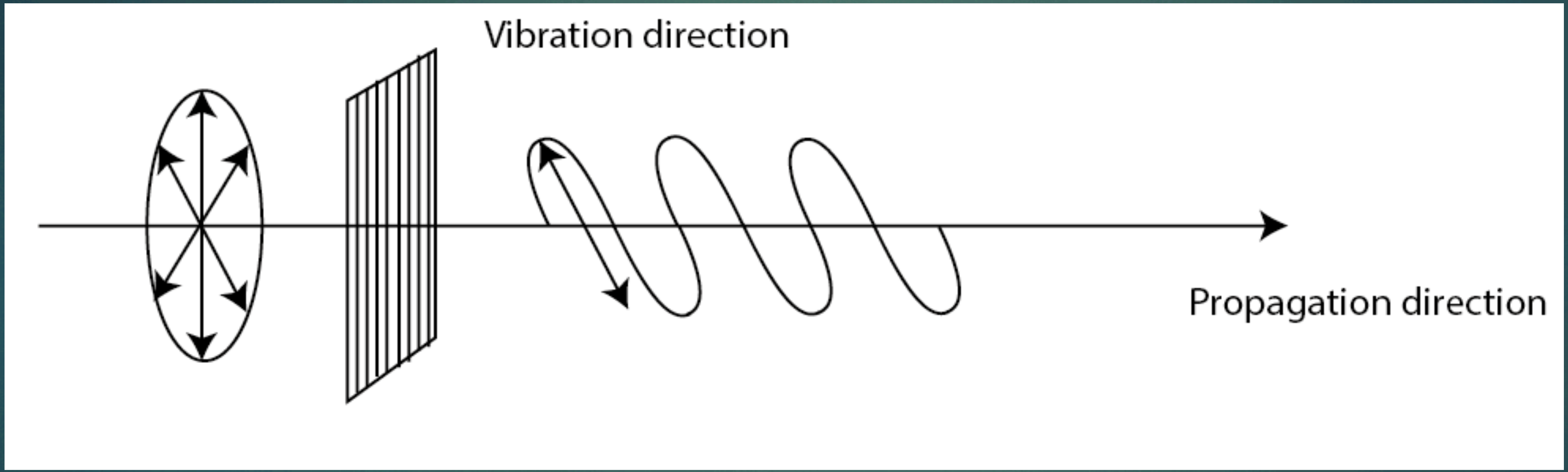
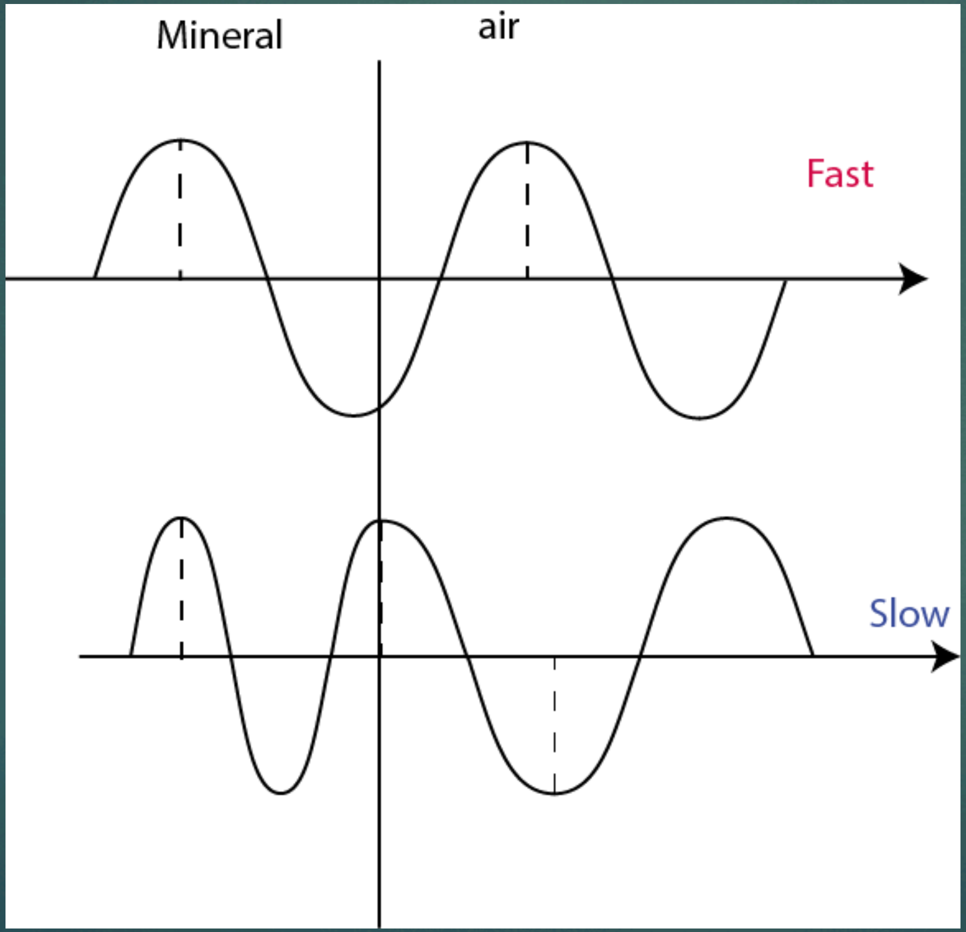


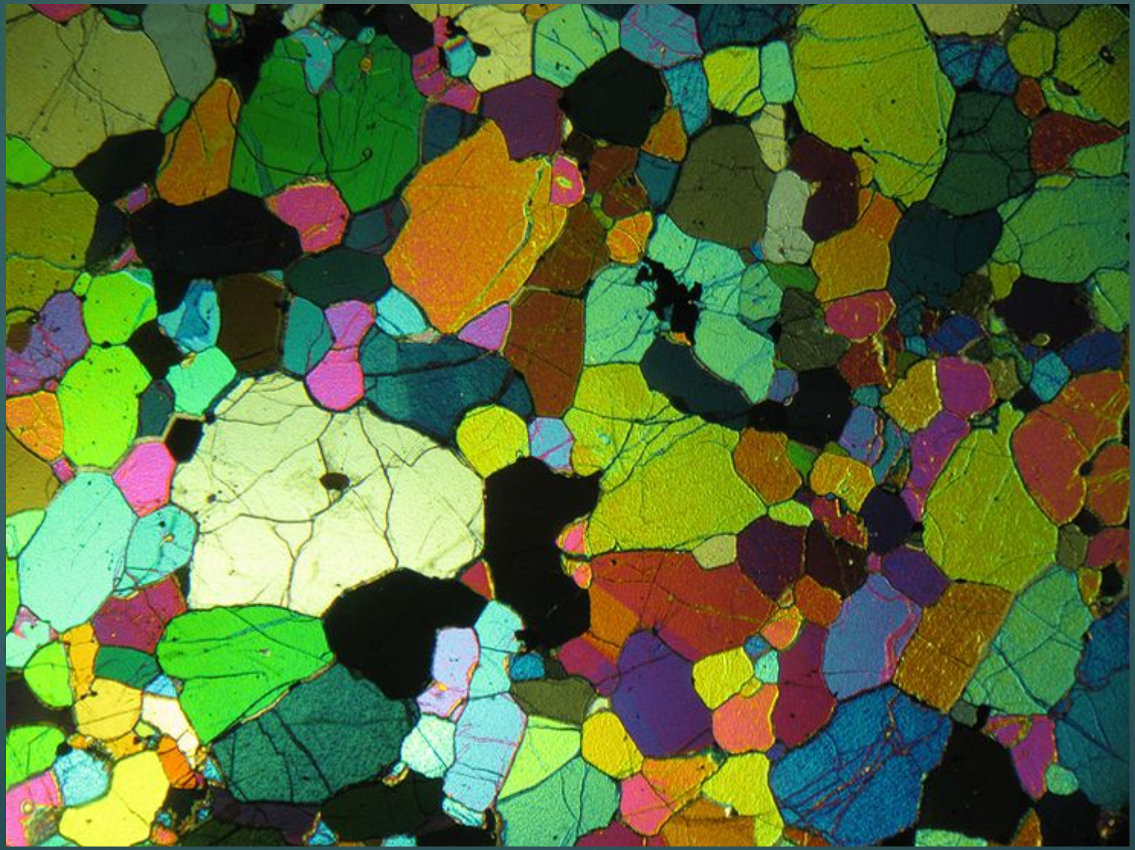
INTERFERENCE PHENOMENA

- **Fast vs. slow ray**



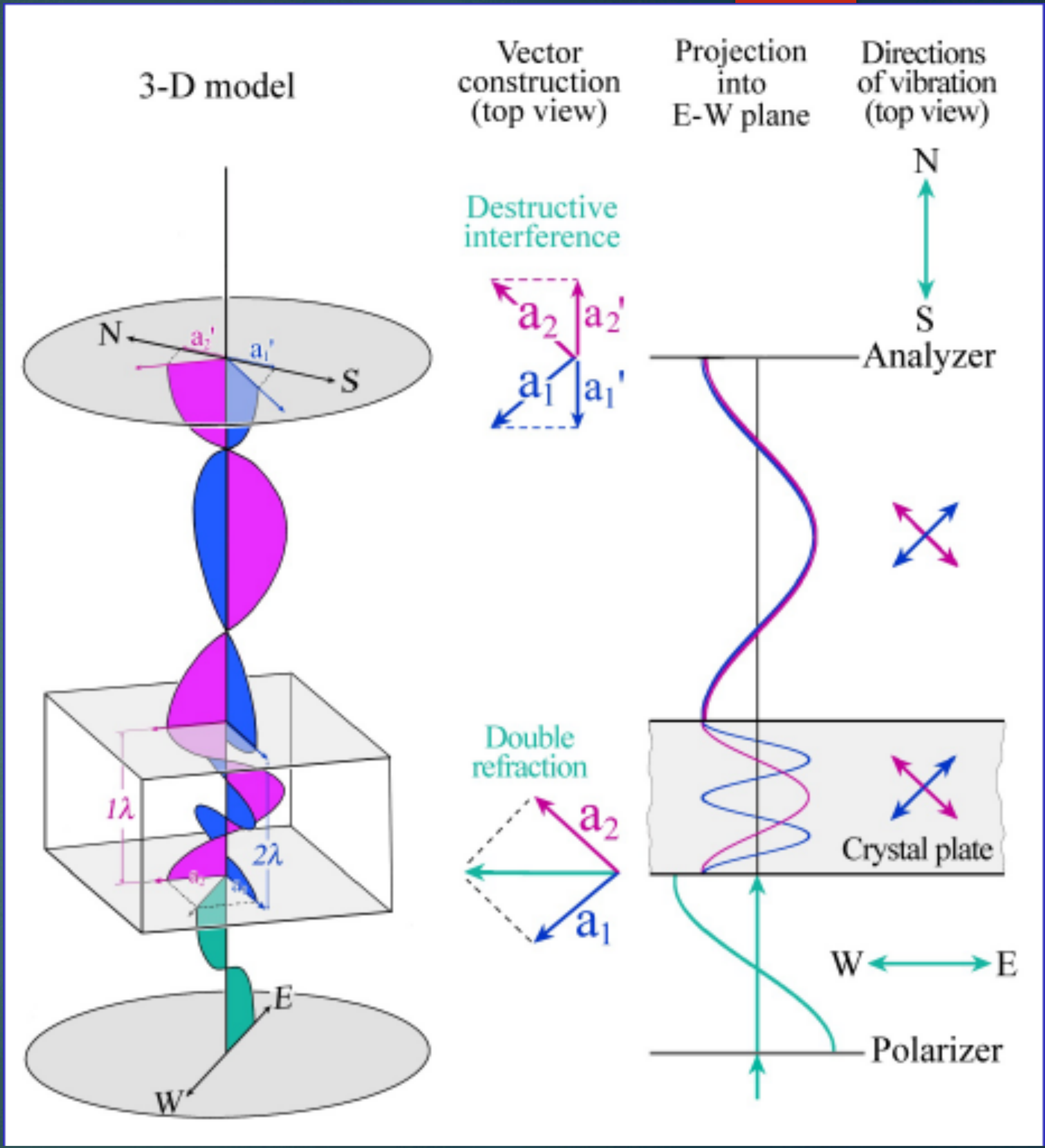
INTERFERENCE PHENOMENA

- **Interference colors (vivid colors in polarized light): produced by birefringence**



INTERFERENCE PHENOMENA

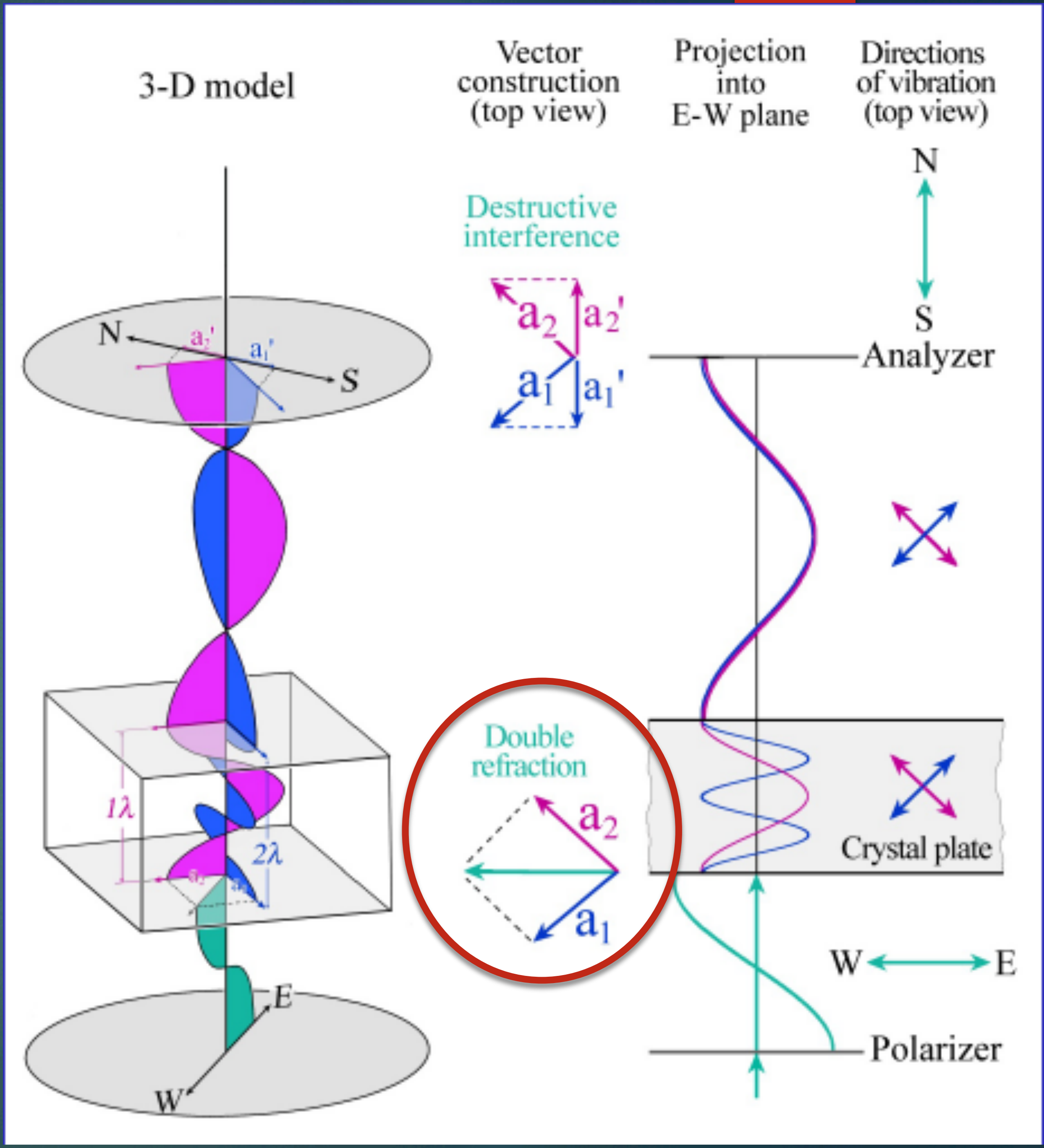
- **Monochromatic illumination**



Guide to thin microscopy Fig. 4.25 A

INTERFERENCE PHENOMENA

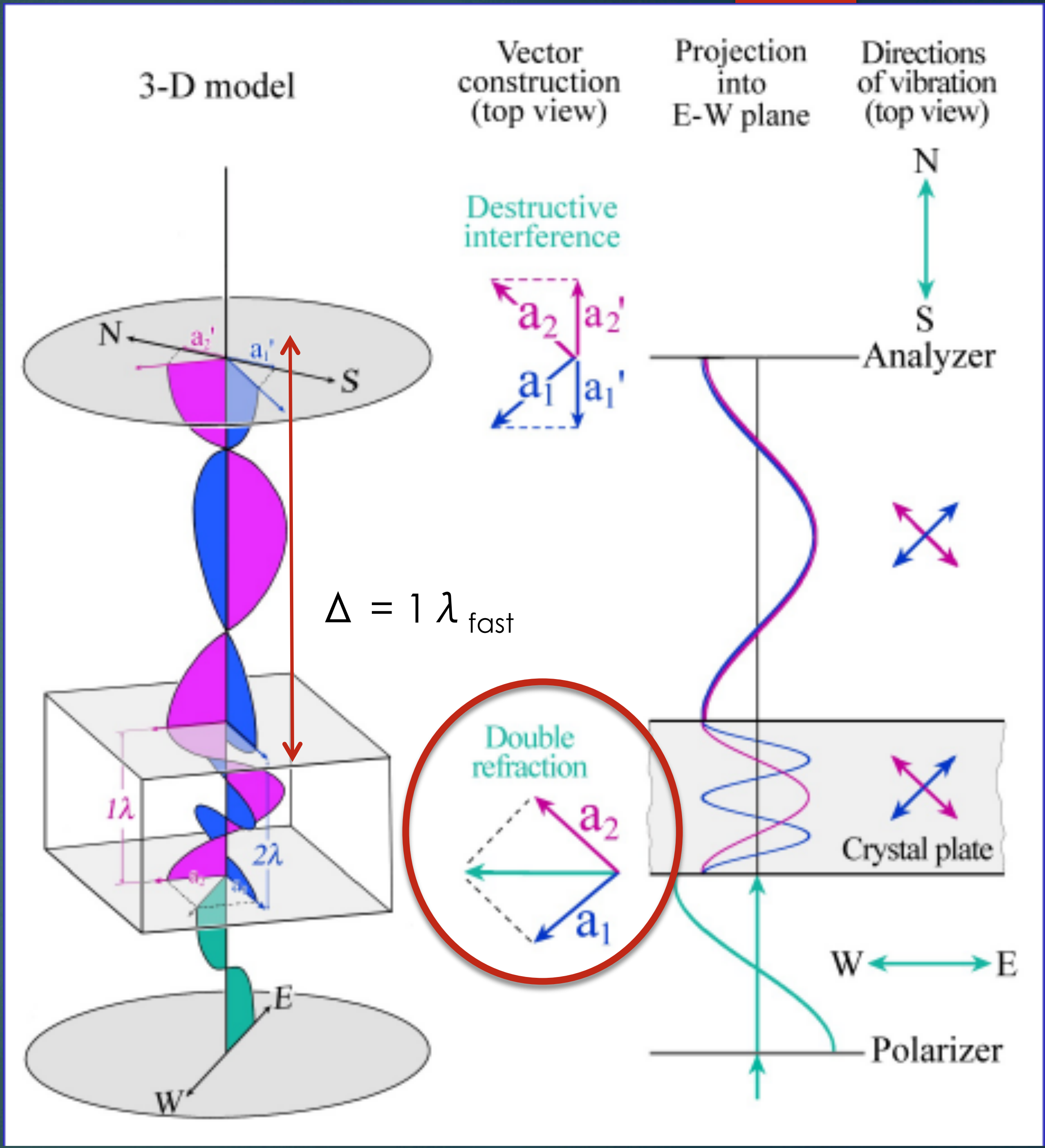
- **Monochromatic illumination**



Guide to thin microscopy Fig. 4.25 A

INTERFERENCE PHENOMENA

- **Monochromatic illumination**
  - **Retardation Δ:** distance that the fast ray travel outside the mineral when the slow ray emerge from the mineral.
  - Depends on thickness of the mineral and difference of velocities



Guide to thin microscopy Fig. 4.25 A

INTERFERENCE PHENOMENA

- **Monochromatic illumination**
  - **Retardation Δ**

Vs: velocity of the slow ray, Vf: velocity of the fast ray, d: thickness

ts = d/Vs: time for the slow ray to travel through the crystal

INTERFERENCE PHENOMENA

- **Monochromatic illumination**
  - **Retardation Δ**

Vs: velocity of the slow ray, Vf: velocity of the fast ray, d: thickness

ts = d/Vs: time for the slow ray to travel through the crystal

During the same duration, the fast ray travel through the crystal and also travel to a distance equal to Δ

$ts = d/Vs = d/Vf + \Delta / V_{air}$

INTERFERENCE PHENOMENA

- **Monochromatic illumination**
  - **Retardation Δ**

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ts = d/Vs: time for the slow ray to travel through the crystal

$ts = d/Vs = d/Vf + \Delta / V_{air}$

Assuming $V_{air} = V_{vacuum} = c$

$\Delta = d * (c/Vs - c/Vf)$

INTERFERENCE PHENOMENA

- **Monochromatic illumination**
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$ts = d/Vs = d/Vf + \Delta/V_{air}$

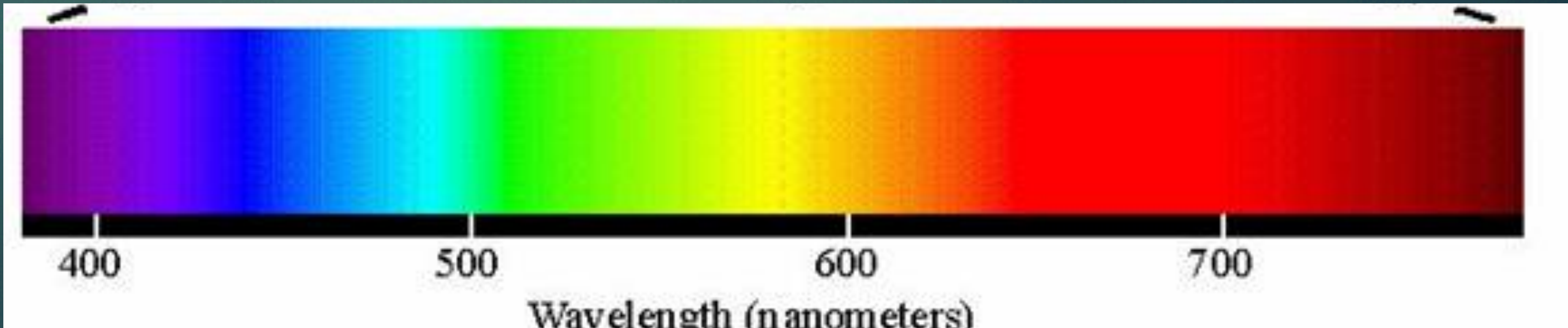
Assuming $V_{air} = V_{vacuum} = c$

$\Delta = d * (c/Vs - c/Vf)$

$\boldsymbol{\Delta = d * (ns - nf)}$

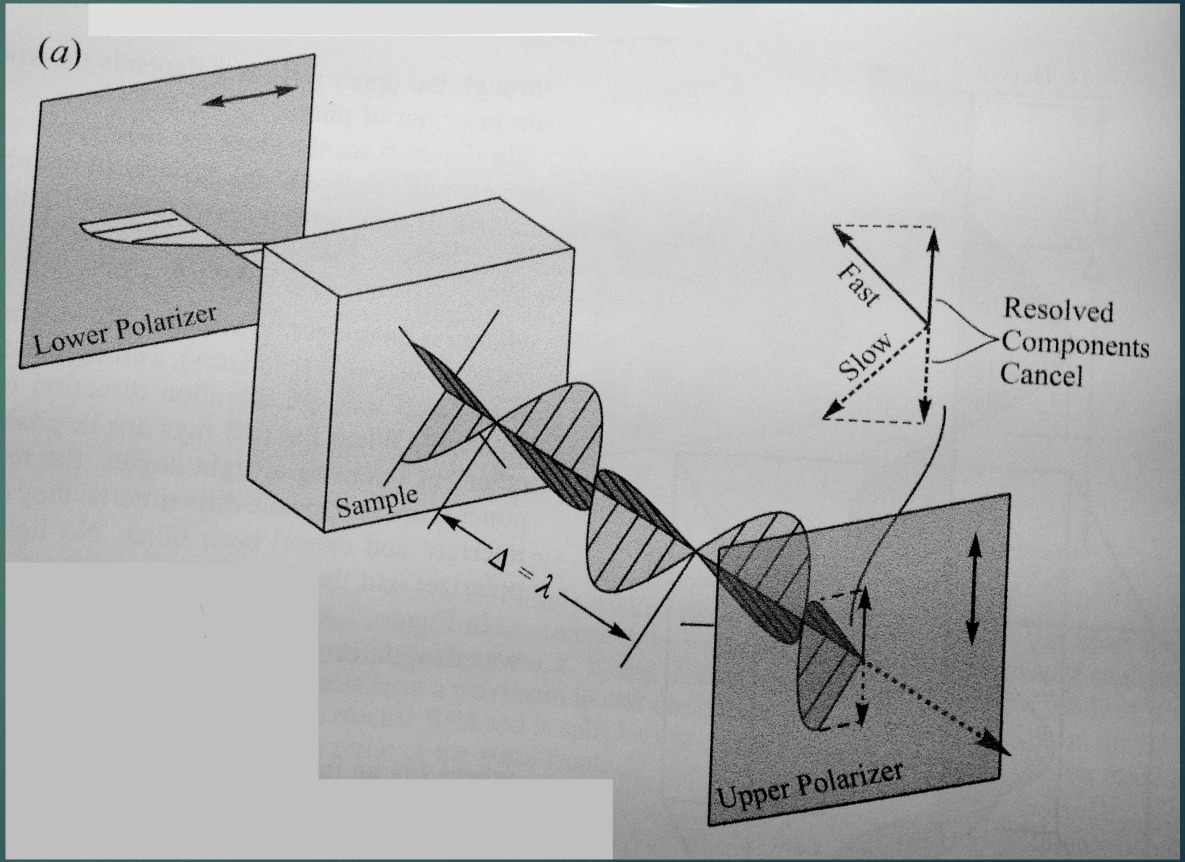
INTERFERENCE PHENOMENA

- **Monochromatic illumination**
  - **Retardation $\Delta = d * (n_s - n_f)$**
  - **Birefringence $\delta = n_s - n_f$:** difference between the indices of refraction of the slow and the fast.
    - Maximal value ⇔ mineral characteristic
    - Depends on the wavelength of the light. Default value: 589 nm



INTERFERENCE PHENOMENA

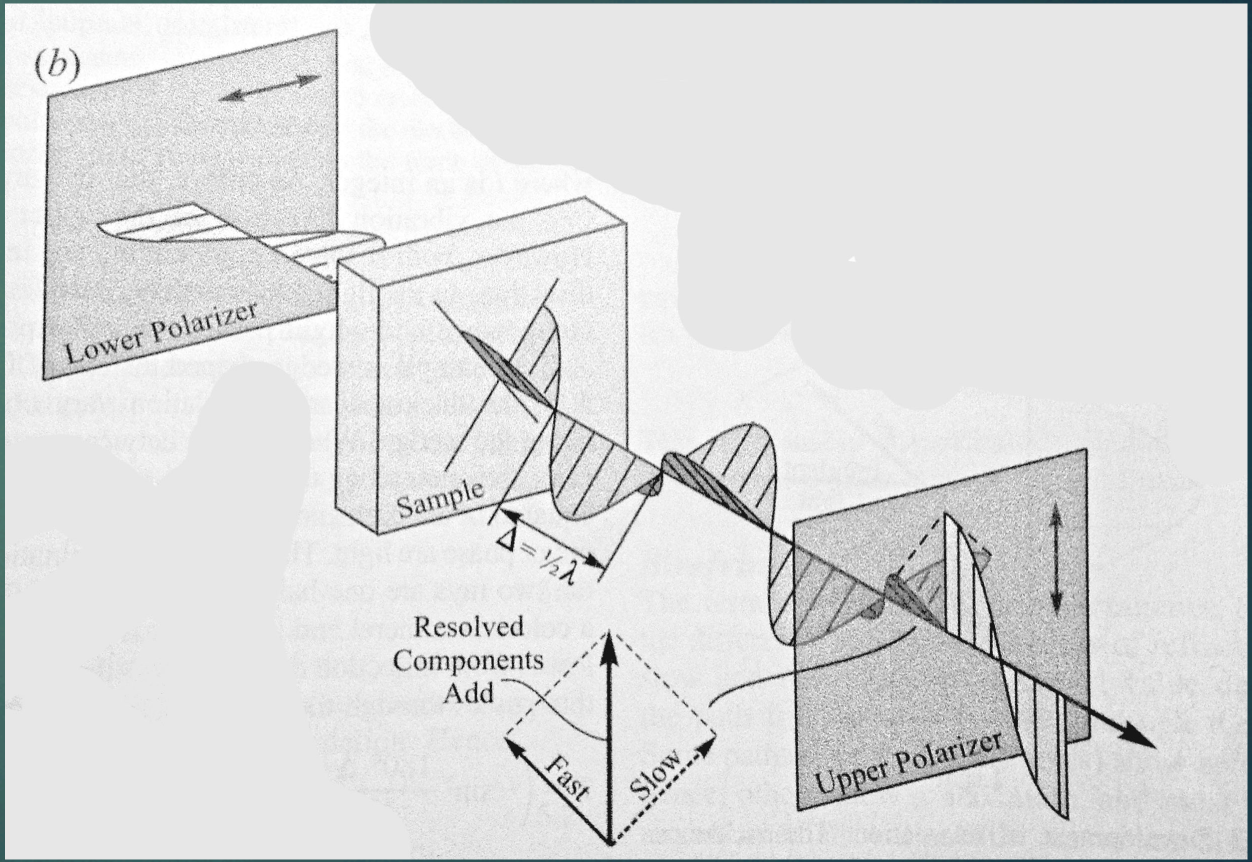
- **Monochromatic illumination**
  - **Interference of two rays:**
    - In phase: $\Delta = i\lambda \Rightarrow$ extinction (the mineral appears black)



Nesse Fig. 5.4

INTERFERENCE PHENOMENA

- **Monochromatic illumination**
  - **Interference of two rays:**
    - Out of phase:
      ex.: $\Delta = 1/2\,\lambda$



Nesse Fig. 5.4

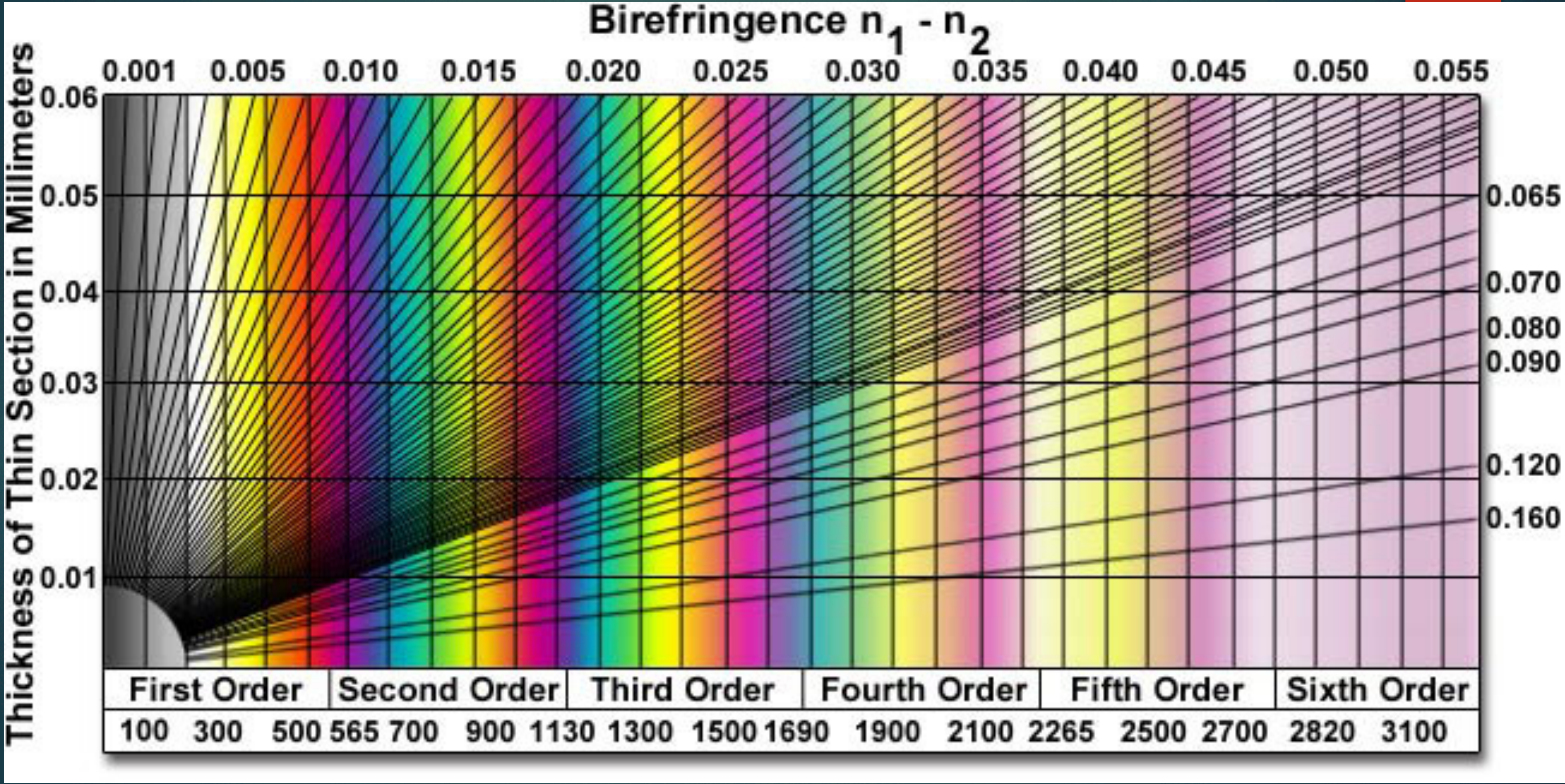
INTERFERENCE PHENOMENA

- **Monochromatic illumination**
  - **Interference of two rays:**
    - In phase: the mineral is extinct
    - Out of phase: the light passes through the polariseur

INTERFERENCE PHENOMENA

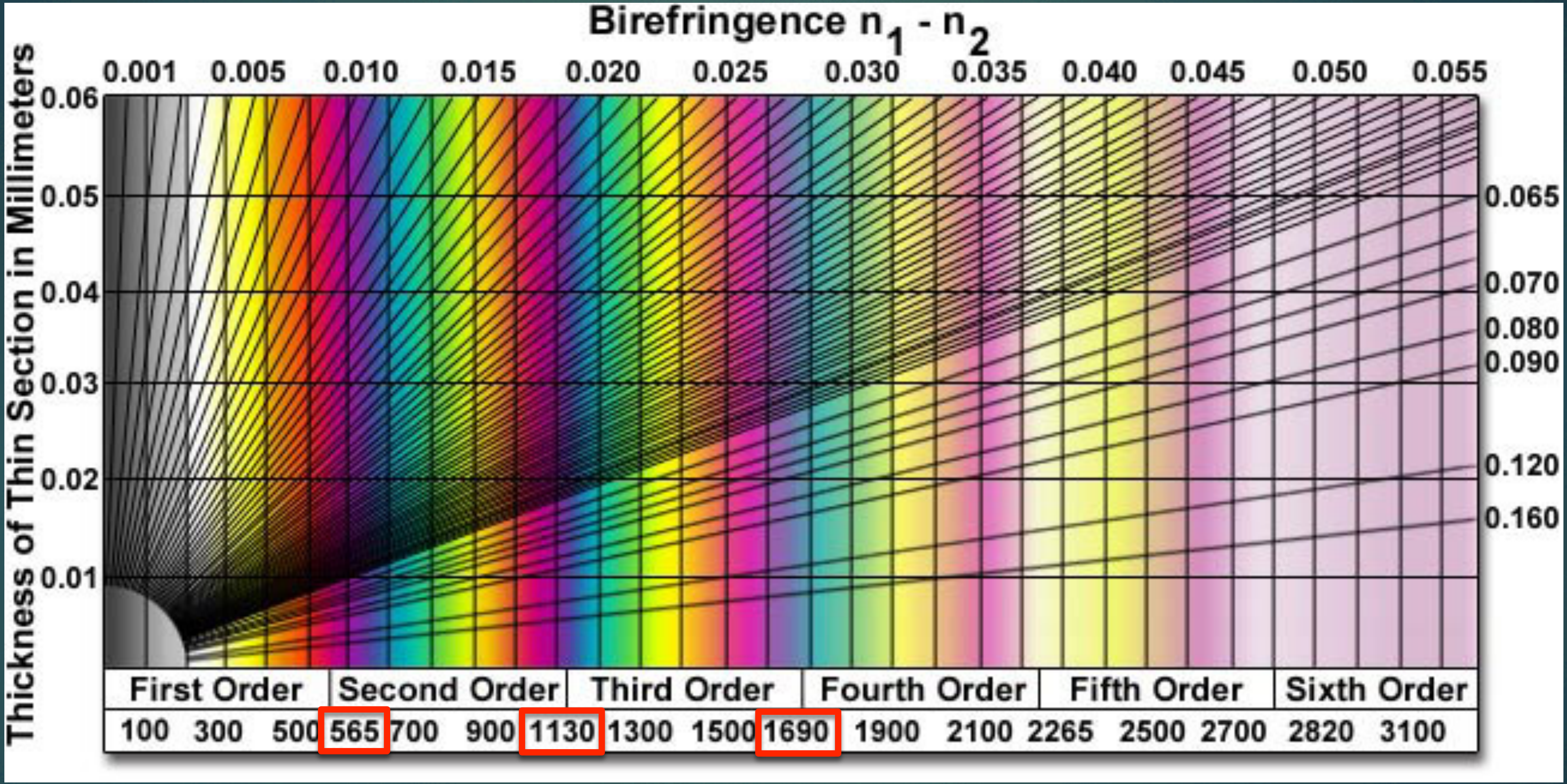
- **Polychromatic illumination**
  - Presence of all the wavelengths
  - About the same Δ for each wavelength.
  - Color depends on the thickness and on the orientation of the crystal

INTERFERENCE PHENOMENA



INTERFERENCE PHENOMENA

- **Order of interference colors**

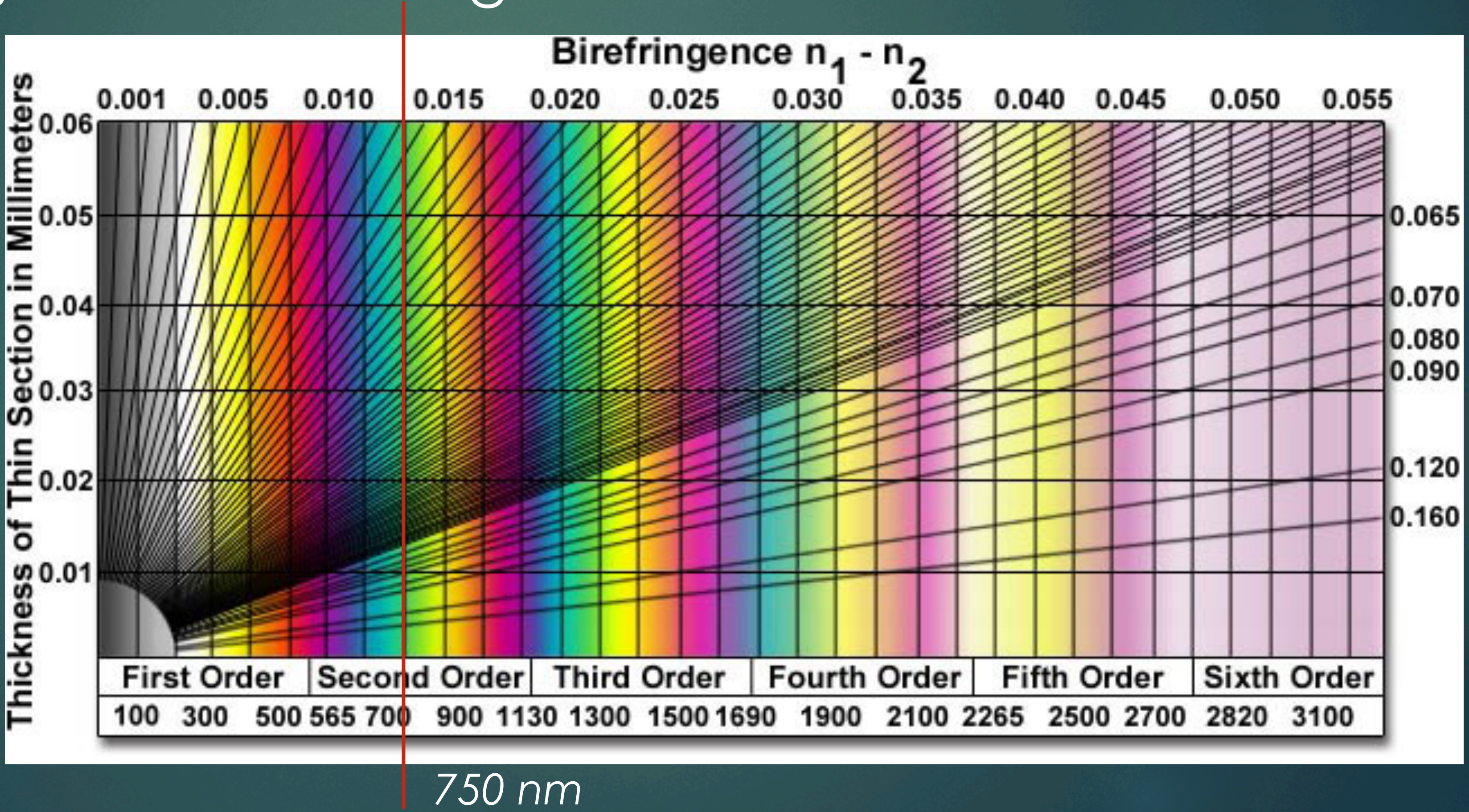


BIREFRINGENCE COLOR

- **Determination of the thickness of a sample:**
  - See Nesse p. Chapter 5, p. 47-48
  - Typical thickness of a thin section : **0.03 mm**

BIREFRINGENCE COLOR

- **Determination Birefringence form the color chart (plate 1)**
  - Find the grains with the highest order of interference color.



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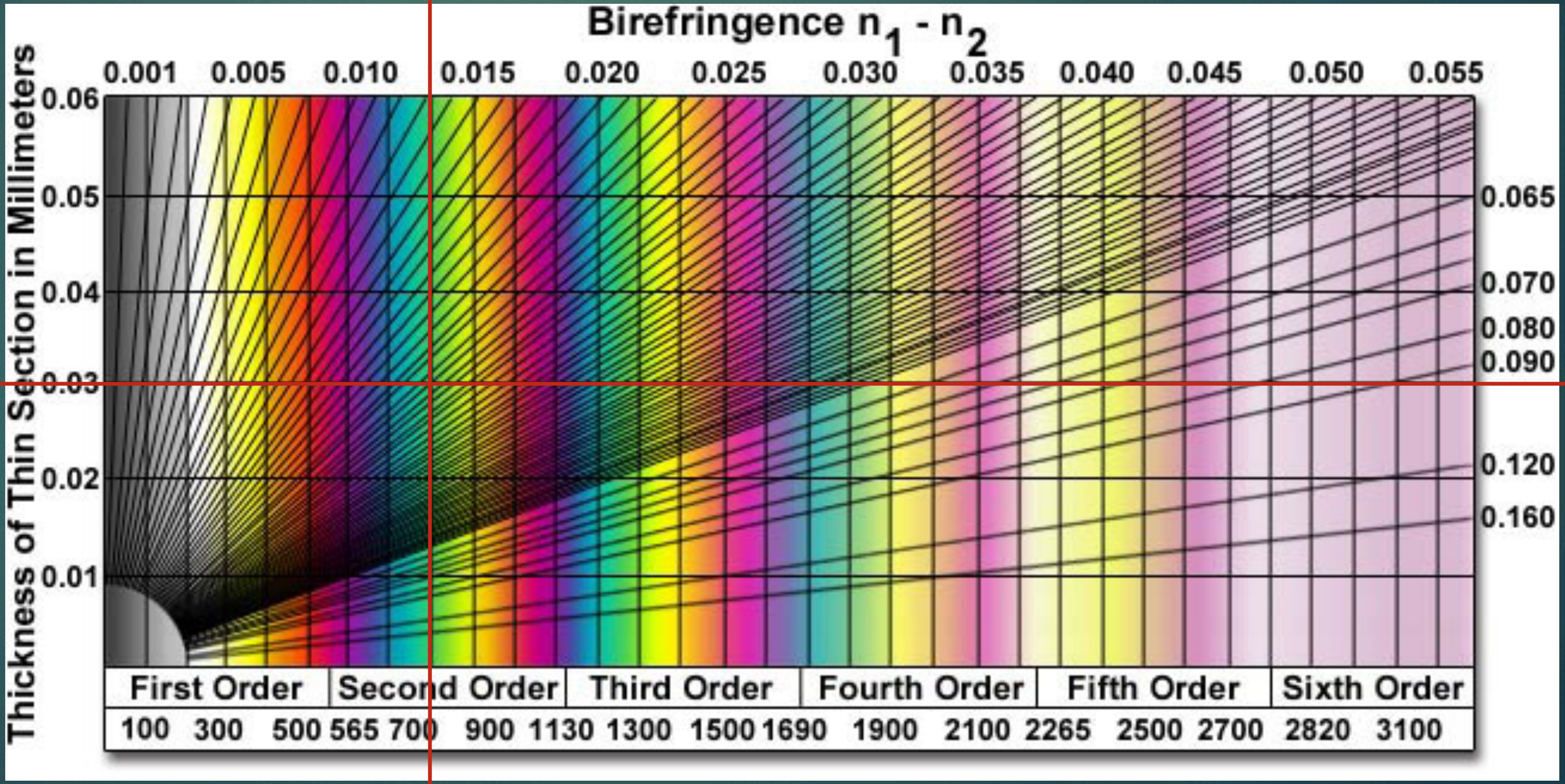

750 nm

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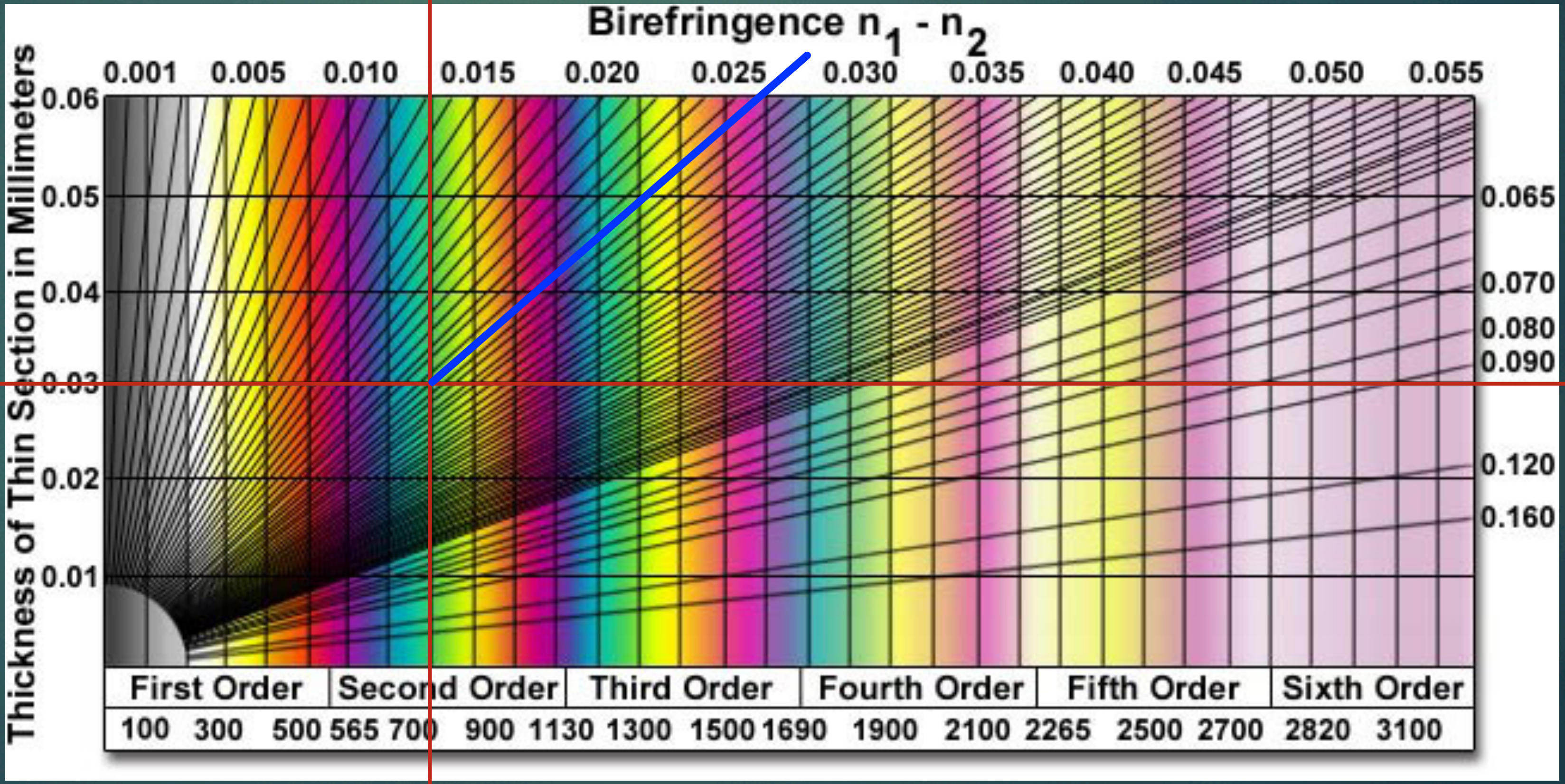


750 nm

BIREFRINGENCE COLOR

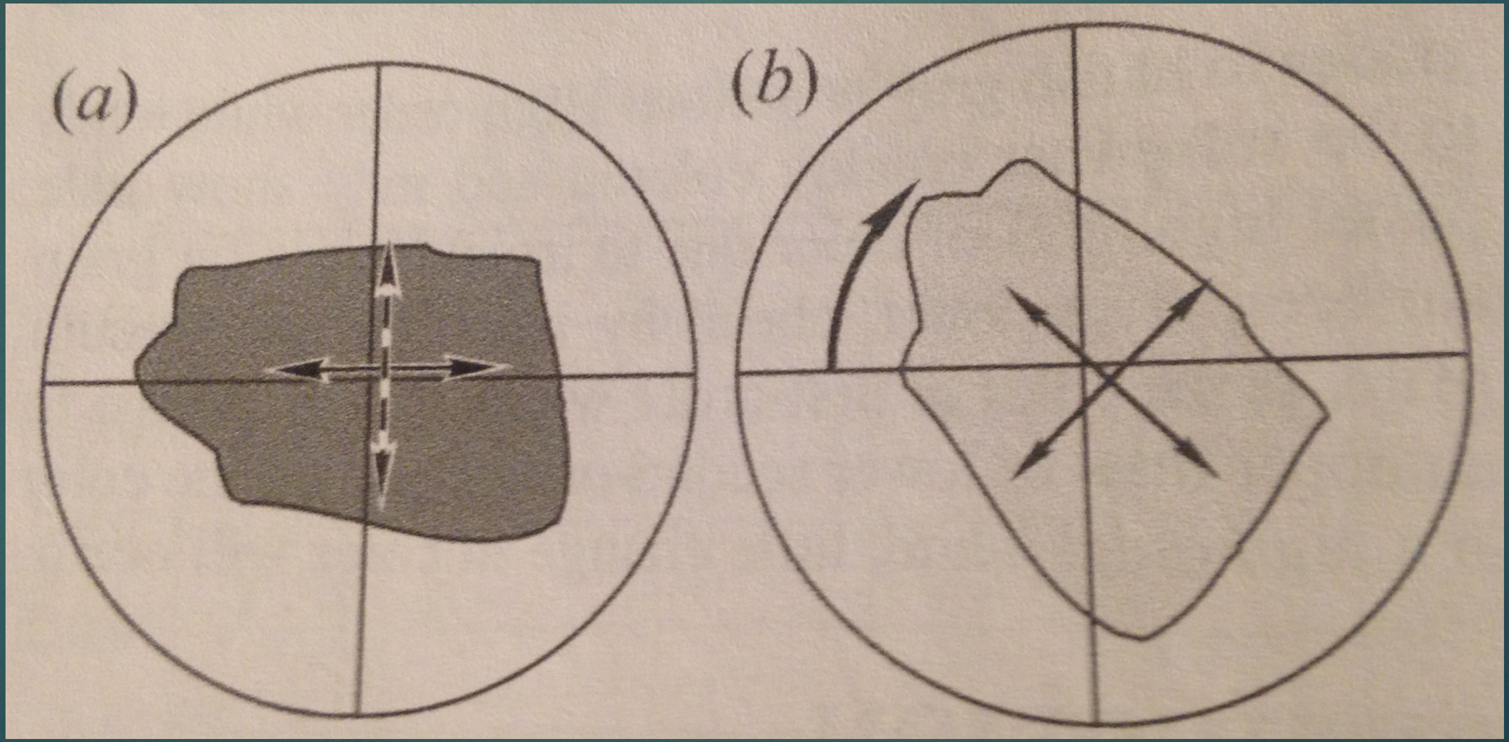
- **Determination Birefringence form the color chart (plate 1)**
  - Find the grains with the highest order of interference color.
- **Issues:**
  - The thickness of the thin section is not always known.
  - The thickness of one particular mineral can be bigger ⇒ apparent high order of birefringence color

EXTINCTION

- **The optic axis**
- An optic axis is a straight line through a mineral along which light does not diverge into two separate rays
- Corresponds to an axis of symmetry such that the speed light would be the same no matter what direction the ray vibrates
- Along the optic axis the mineral behaves as if it were isotropic (no retardation)

EXTINCTION

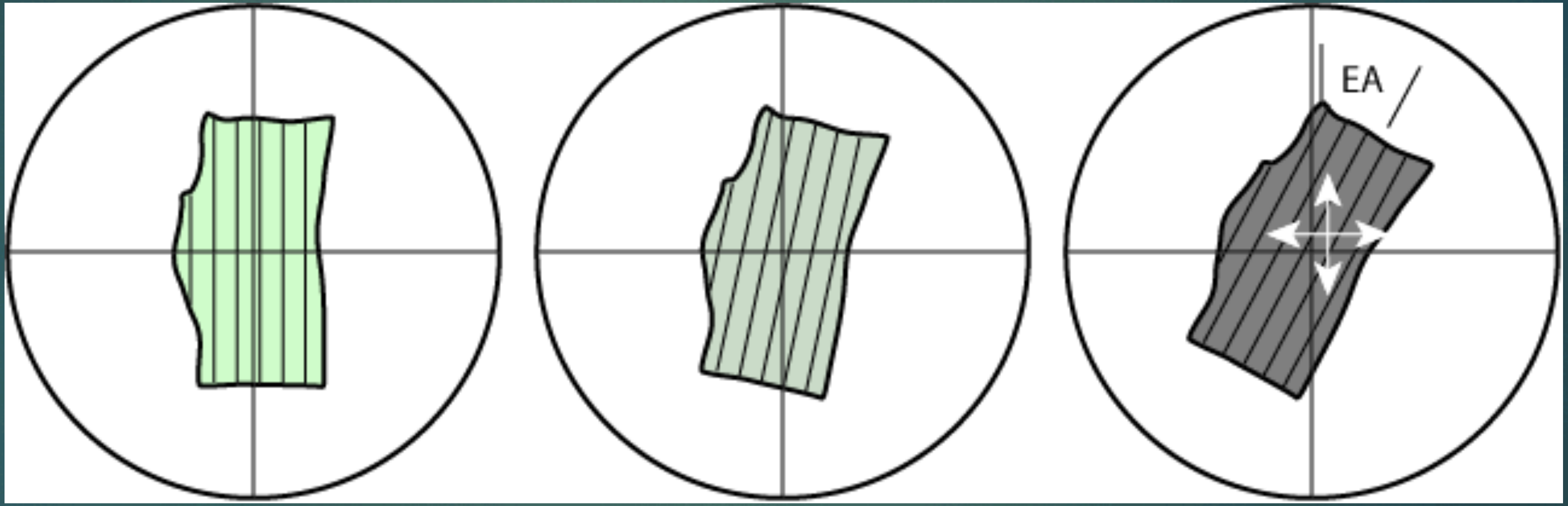
- **Extinction:**
  - When the mineral section is perpendicular to an optic axis
  - Every 90° of rotation of the microscope stage



Nesse Fig. 5.9

EXTINCTION

- **Extinction angle:** angle between the length of the mineral or the cleavage of a mineral and one of the vibration direction

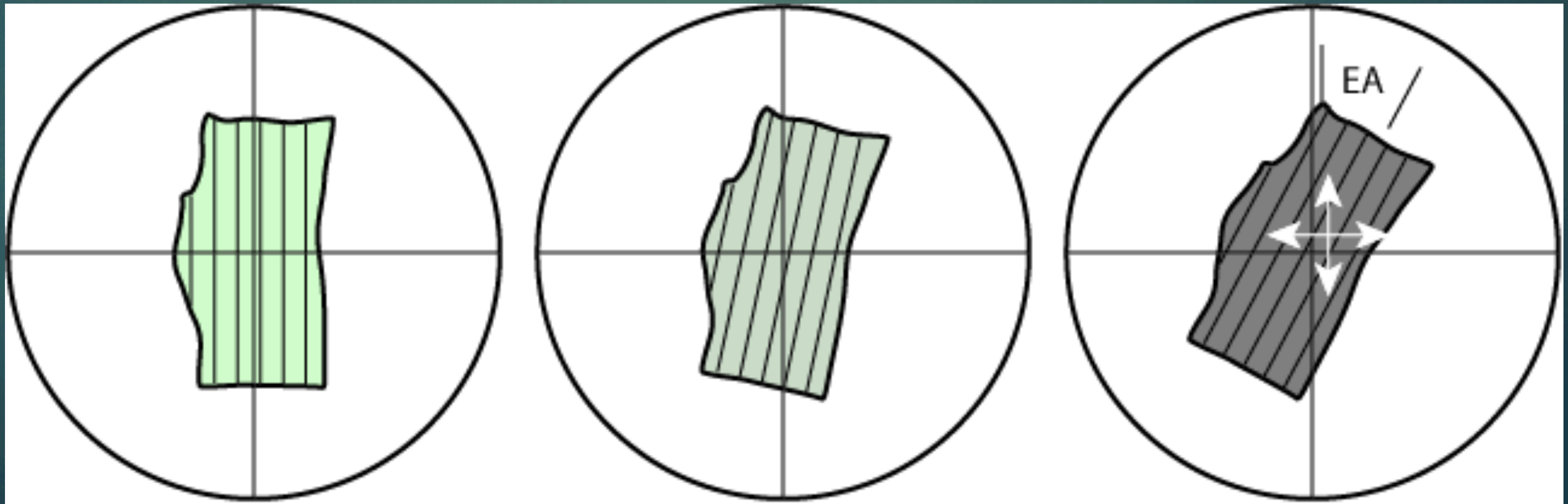


EXTINCTION

- **Extinction angle:** angle between the length of the mineral or the cleavage of a mineral and one of the vibration direction

- 1) rotate the stage until the length or cleavage is aligned with the N-S direction of the crosshair

- 2) rotate the stage until the mineral go extinct



EXTINCTION

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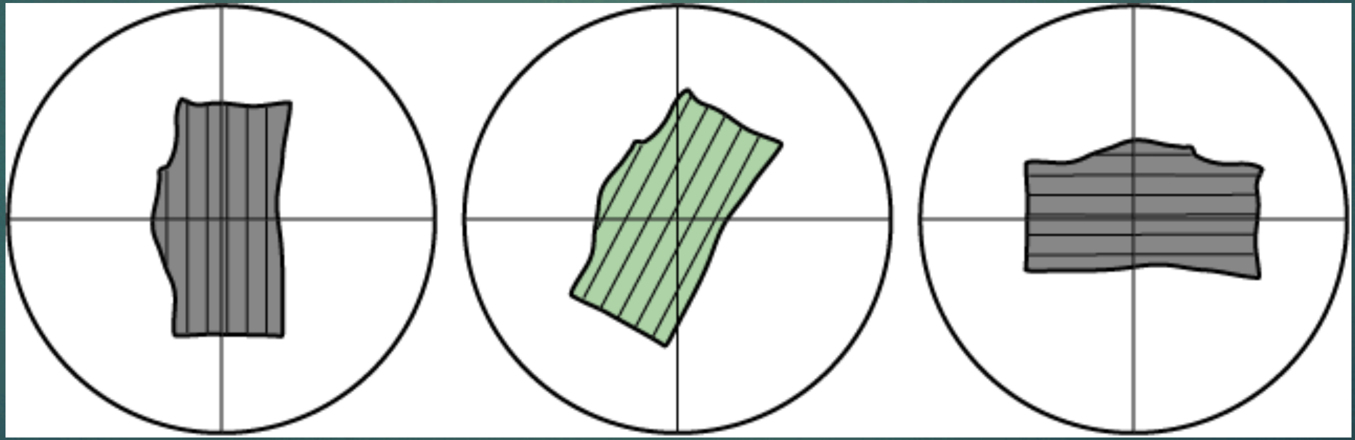
- 1) rotate the stage until the length or cleavage is aligned with the N-S direction of the crosshair

- 2) rotate the stage until the mineral go extinct

- 3) Note that if the extinction angle determined with clockwise rotation is EA, the extinction angle determined with counterclockwise rotation is 90°-EA. <u>Report the smallest one.</u>

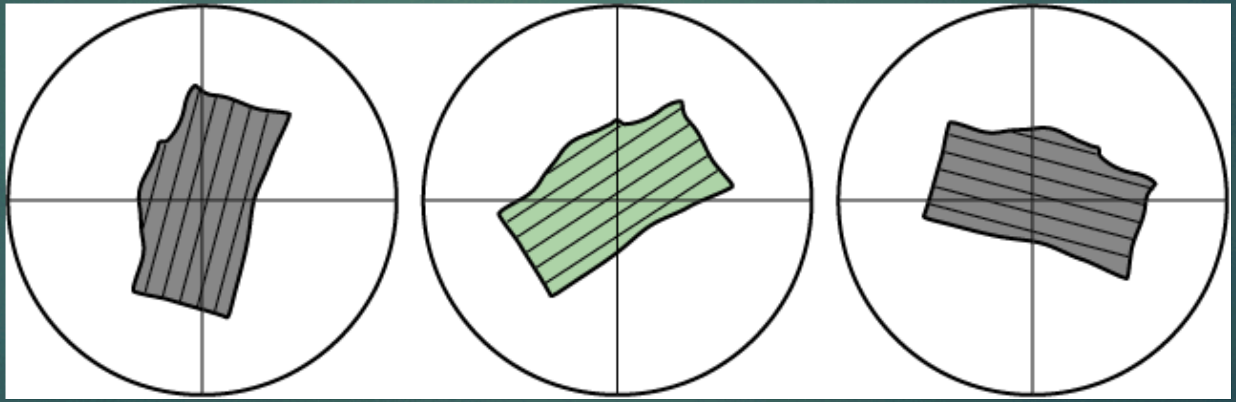
EXTINCTION

- **Extinction angle:**
  - **Parallel extinction** The extinction angle is zero: the mineral is extinct when the cleavage or the length is aligned with one og the crosshairs.



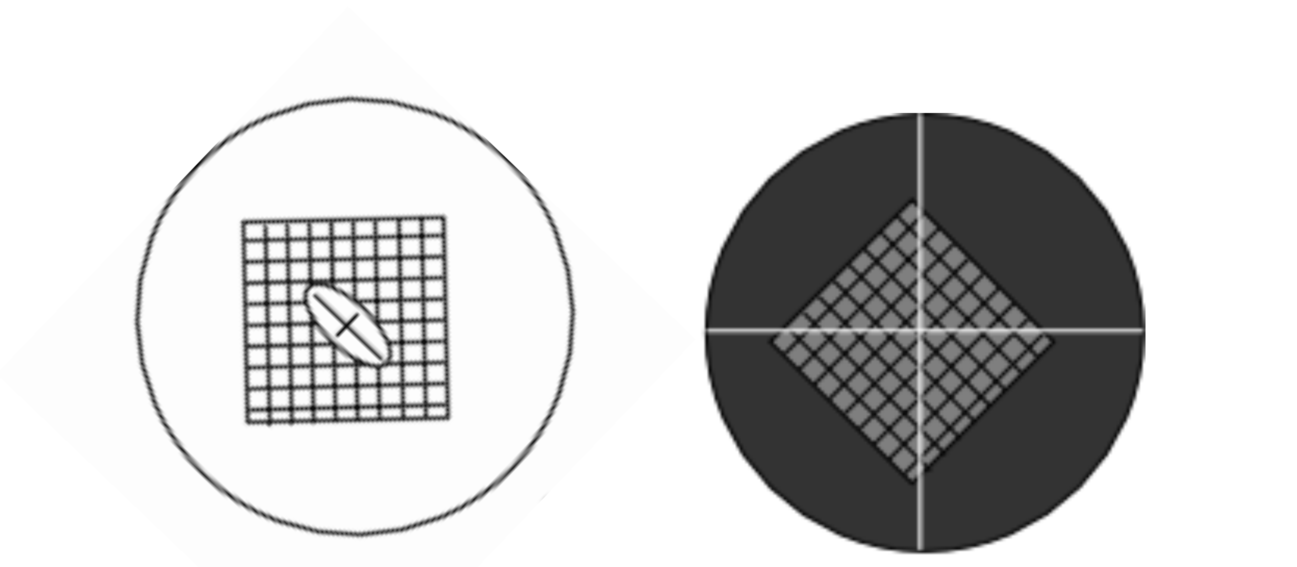
EXTINCTION

- **Extinction angle:**
  - **Inclined extinction** The extinction angle is not zero: the mineral is extinct when the cleavage or the length form some angle with the crosshairs.



EXTINCTION

- **Extinction angle:**
  - **Symmetrical extinction** Some mineral have two different cleavages or two well developed faces. So we can measure to extinction angles. If the two extinction angles are the same, the mineral display symmetrical extinction



Symmetrical Extinction

EXTINCTION

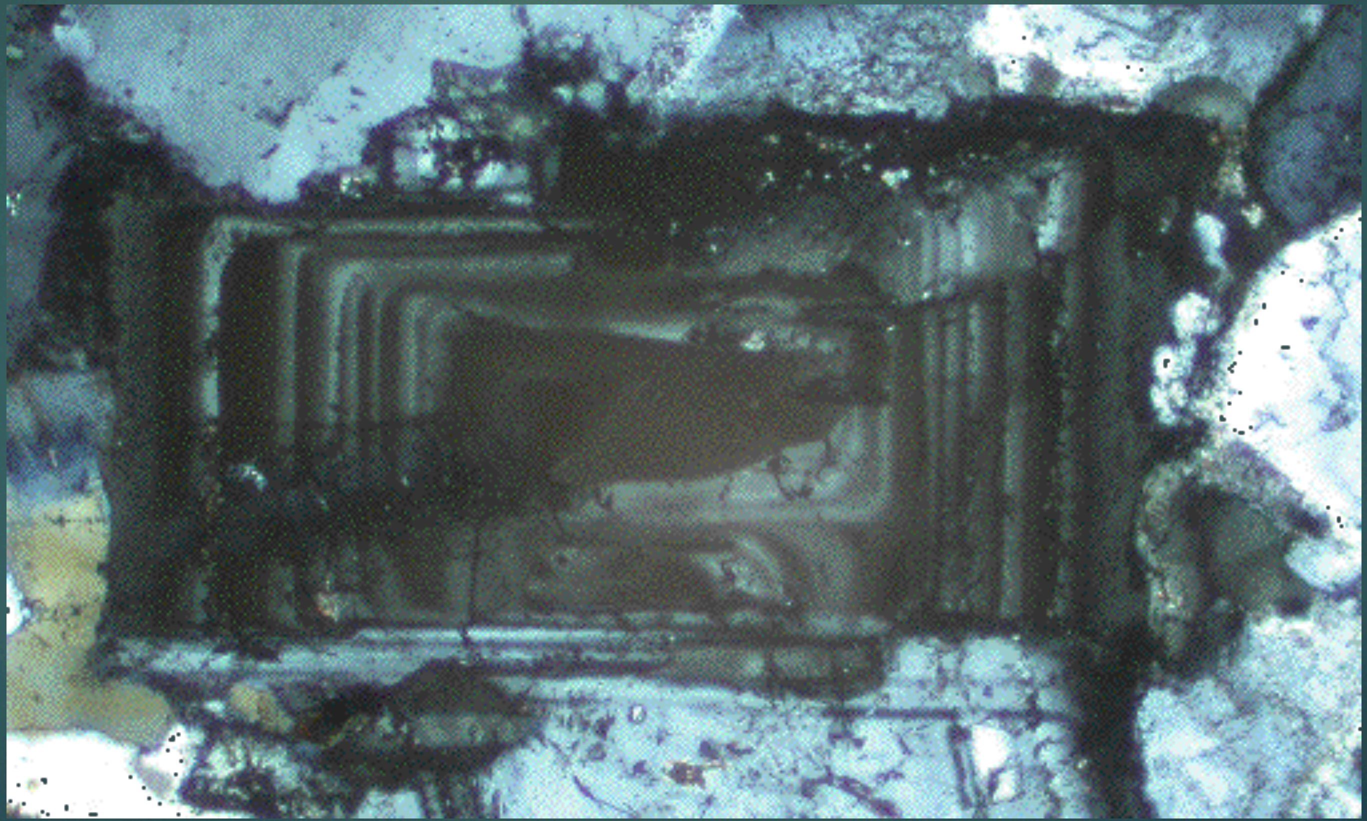
- **Extinction angle:**
  - **No extinction angle** No well developed face, apparent cleavage

EXTINCTION

- **Extinction angle:**
  - **Undulatory extinction** : due to the strain – different part of a sigle grain are in slightly different orientations

EXTINCTION

- **Extinction angle:**
  - Case of the zoned crystal



ACCESSORY PLATES

- **Nesse: Chapter 5. p51-54**
- To determine which of the two rays coming from the mineral is the fast ray and which is the slow ray.

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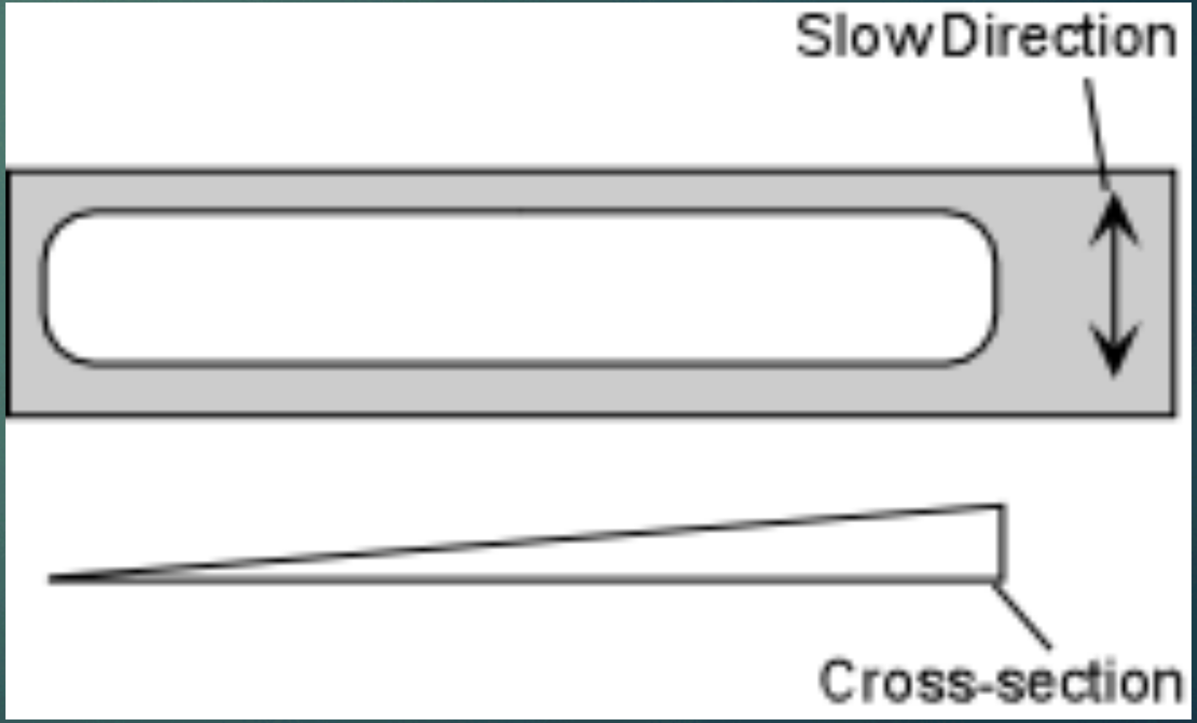
- **Quartz Wedge**
  - Δ = 0 (1° black) to
    3800 nm (5° green)



ACCESSORY PLATES

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- **Quarter wedge plate or mica plate:** Δ = 150 nm (1° gray)

ACCESSORY PLATES

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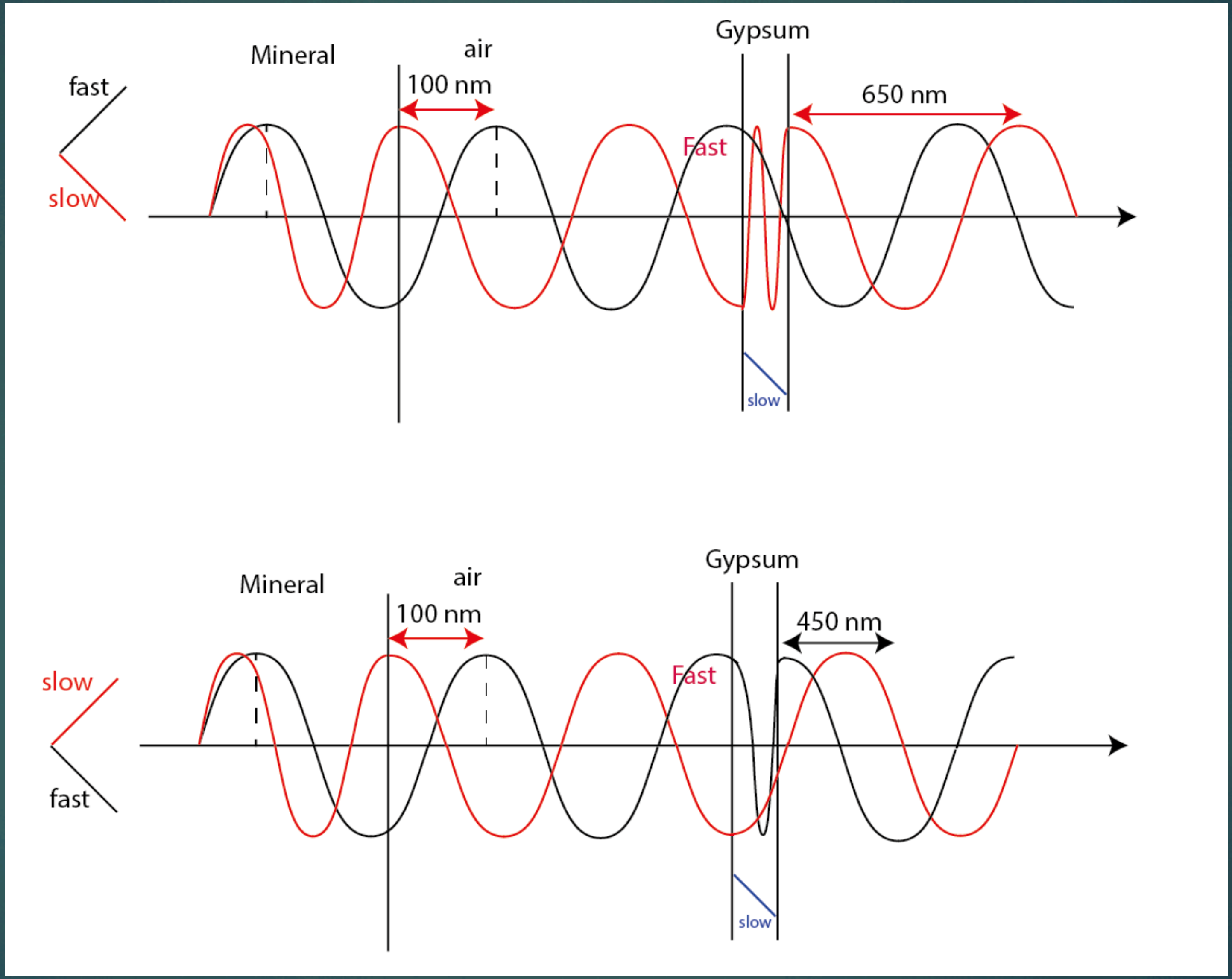
- **Quartz wedge:** Δ = 0 (1° black) to 3800 nm (5° green)
- **Quarter wedge plate or mica plate:** Δ = 150 nm (1° gray)
- **Full wedge plate or gypsum plate:** Δ = 550 nm (1° red)

ACCESSORY PLATES

- **Use of the gypsum plate**
- To determine which of the two rays coming from the mineral is the fast ray and which is the slow ray.
- 1) orientation of the crystal: vibration direction oriented at 45° to the polarizing direction of the microscope.
- 2) insert the plate.
  - If the degree of the interfere color increases (to the right in plate 1), it's an addition: the chosen vibration direction is the slow axis
  - If the degree of the interference color decreases (to the left), it's a substraction: the chosen vibration direction is the fast axis

ACCESSORY PLATES



ACCESSORY PLATES

- **Sign of elongation**
- Length slow: the slow ray vibrates more or less parallel to the length of elongation (or cleavage) = positive elongation.
- Length fast: the fast ray vibrates more or less parallel to the length of elongation (or cleavage) = negative elongation.

ACCESSORY PLATES

- **Sign of elongation**
- In practice
  - 1) if the direction in which the degree of the interference color increases when we the gypsum plate is inserted, is more or less parallel to the direction of elongation or cleavage: **positive elongation**
  - 2) If the direction in Δ decreases when we the gypsum plate is inserted, is more or less parallel to the direction of elongation or cleavage: **negative elongation**

PLEOCHROISM

- Change of color in transmitted light:
- Different absorptions between the two rays of light as they pass through the colored mineral

For next week:

- **Reading: Chap 6 in Introduction to Optical Mineralogy**

Lab:

- **Extinction angle**
- **Interference colors**
- **Accessory plates**
- **Sign of elongation**