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1. Learning outcomes

After studying this module student will be able to

1. Appreciate the phenomenon of Interference of light.
2. Apply Michel Levy Chart for determining order of interference colour and Birefringence.

2. Introduction

In optically anisotropic minerals, the electronic environment is known to vary with direction so velocity of light travelling varies with direction too. As a consequence, anisotropic minerals show **double refraction (Fig. 1)** which means that light entering an anisotropic mineral in most directions is split into two rays with different velocities, which vibrate at right angles to each other. If the light velocity of the two rays is determined by measuring indices of refraction one ray is found to be faster than the other. The ray with the lower index of refraction is the fast ray and the one with the higher index of refraction is slow ray. Every anisotropic mineral has either one or two directions called optic axes along which light is not split into two rays. If one such direction is present, a mineral is called as uniaxial and if two such directions are present we call it biaxial mineral.

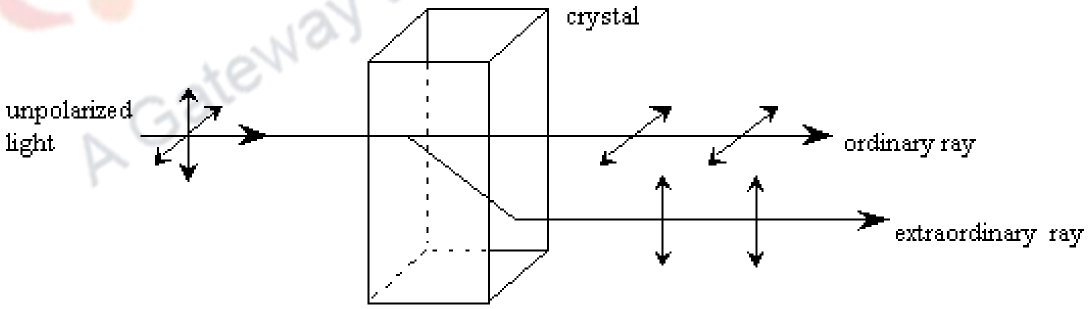

Fig. 1 Schematic representation of double refraction in anisotropic mineral.

3. Phenomena of Interference

An anisotropic mineral is placed on the microscope stage with the polarizers crossed, in most cases light passes the upper polarizer and the mineral displays a color. The colours for an anisotropic mineral observed in thin section, between crossed polars are called interference colours and are produced as a consequence of splitting the light into two rays on passing through the mineral.

3.1. Monochromatic illumination: Monochromatic ray, of plane polarized light, upon entering an anisotropic mineral is split into two rays, the FAST and SLOW rays, which vibrate at right angles to each other. Retardation develops due to differences in velocity the slow ray lags behind the fast ray, and the distance represented by this lagging after both rays have exited the crystal is the retardation –**Δ** (**Fig. 2**). The magnitude of the retardation is dependent on the thickness (d) of the mineral and the differences in the velocity of the slow (V_S) and fast (V_F) rays. The time it takes the slow ray to pass through the mineral is given by:

$$T_S = d/V_S \quad (1)$$

during this same interval of time the fast ray has already passed through the mineral and has travelled an additional distance = retardation.

$$T_S = d/V_F + \Delta/V \quad (2)$$

Substituting equation 1 in 2, yields

$$d/V_S = d/V_F + \Delta/V$$

Rearranging we have

$$\Delta = d(V/V_S - V/V_F), \text{ Since } V/V_S = n_S$$

$$\mathbf{\Delta = d(n_S - n_F)} \quad (3)$$

The relationship **(n_S- n_F)** is called birefringence, given Greek symbol **Δ**, represents the difference in the indices of refraction for the slow and fast rays. In anisotropic minerals one path, along the optic axis, exhibits zero birefringence, others show maximum birefringence, but most show an intermediate value. The maximum birefringence is characteristic for each mineral. Birefringence may also vary depending on the wavelength of the incident light.

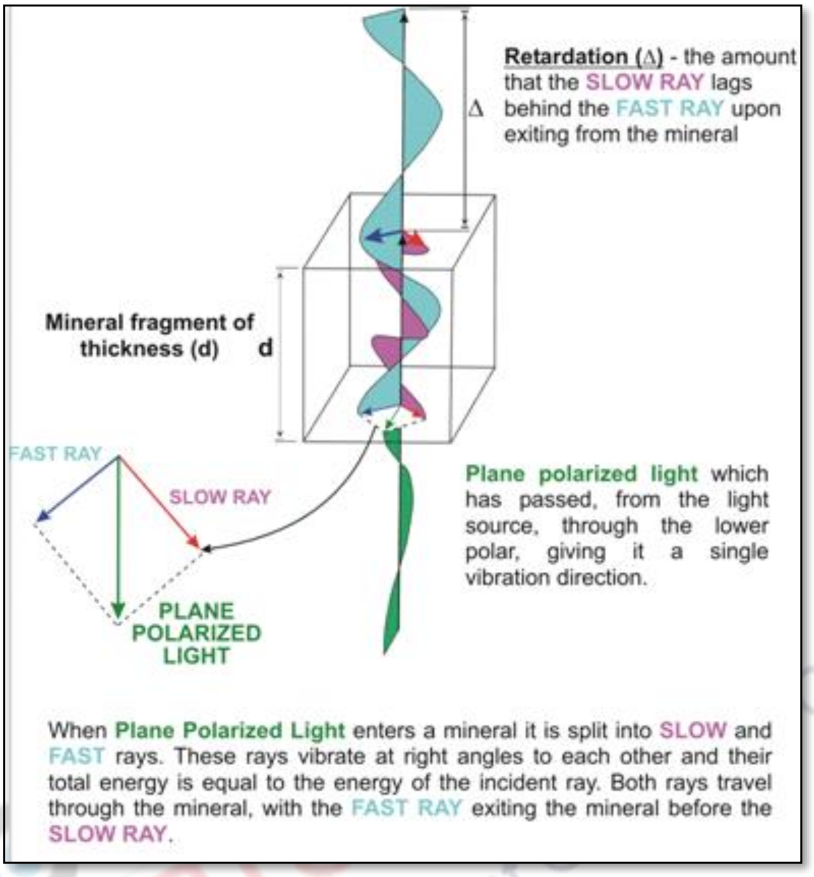

Fig. 2 Schematic showing development of retardation in anisotropic minerals.

Interference phenomena are produced when the two rays are resolved into the vibration direction of the upper polar. Two situations may arise

Case 1: Light passing through lower polar, it gets plane polarized and encounters sample and it gets split into fast and slow rays. If retardation of the slow ray is one whole wavelength, the two emerging waves are "**in phase**". When the light reaches the upper polar, a component of each ray is resolved into the vibration direction of the upper polar. As two rays are in phase, and at right angles to each other, the resolved components are in opposite directions and destructively interfere and cancel each other. Result is no light passes the upper polar and the grain appears black.

Case 2: If retardation of the slow ray behind the fast ray = ½ a wavelength, the two rays are "**out of phase**", and can be resolved into the vibration direction of the upper polar. Both components are in the same direction, so the light constructively interferes and passes the upper polar.

If the mineral sample is wedge shaped instead of flat, the thickness and retardation vary from zero at the thin end to a maximum at the thick end. When placed between crossed polarizers, areas along the wedge where retardation is equal to 0, 1, 2, 3 etc., wavelength (iλ) are dark and areas where the waves have other retardations are light. For a retardation of (i+1/2λ), the wedge shows the brightest illumination (**Fig. 3**).

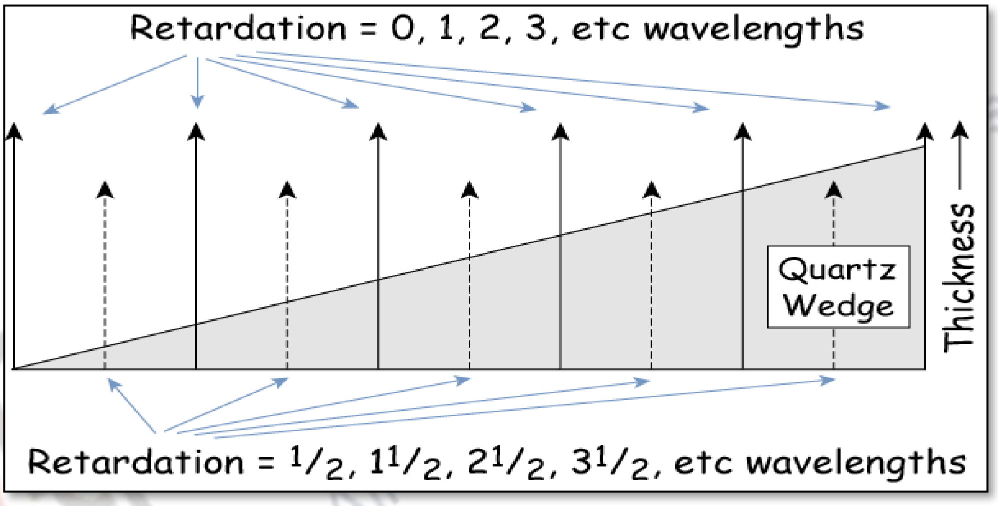

Fig. 3 In a wdege shaped sample the thickness of the sample and the corresponding retardation will vary along the length of the wedge.

3.2. Polychromatic Illumination: Polychromatic light consists of light of a variety of wavelengths, with the corresponding retardation same for all wavelengths. If two rays for some wavelengths reach the upper polar in phase and are canceled, the two rays for other wavelengths reach the upper polar out of phase and are transmitted. The combination of wavelengths that passes the upper polarizer produces **interference colours.** Accessory plates can be used in some cases to determine the order of interference colour.

3.3. Anomalous Interference: Some minerals display interference colors not shown on the interference color chart. We call these anomalous interference colors, which are produced because the dispersion of refractive indices for the fast and slow rays is substantially different. This results in substantially different retardation for short-wavelength light than for long-wavelength light. A different complement of wavelengths reaches the eye than if the retardation were uniform for all wavelengths and the eye therefore perceives the colour differently.

4. Interference colour chart

Examining the quartz wedge between crossed polars in polychromatic light produces a range of colours. This colour chart is referred to as the Michel Levy Chart (**Fig. 5**). At the thin edge of the wedge the thickness and retardation are ~ 0, all of the wavelengths of light are cancelled at the upper polarizer resulting in a black colour. With increasing thickness (increasing retardation), the interference colour changes from black to grey to white to yellow to red and then a repeating sequence of colours from blue to green to yellow to red (**Fig. 6**). The colours get paler, more washed out with each repetition. The interference colour produced is dependent on the wavelengths of light, which pass the upper polar, and the wavelengths, which are cancelled.

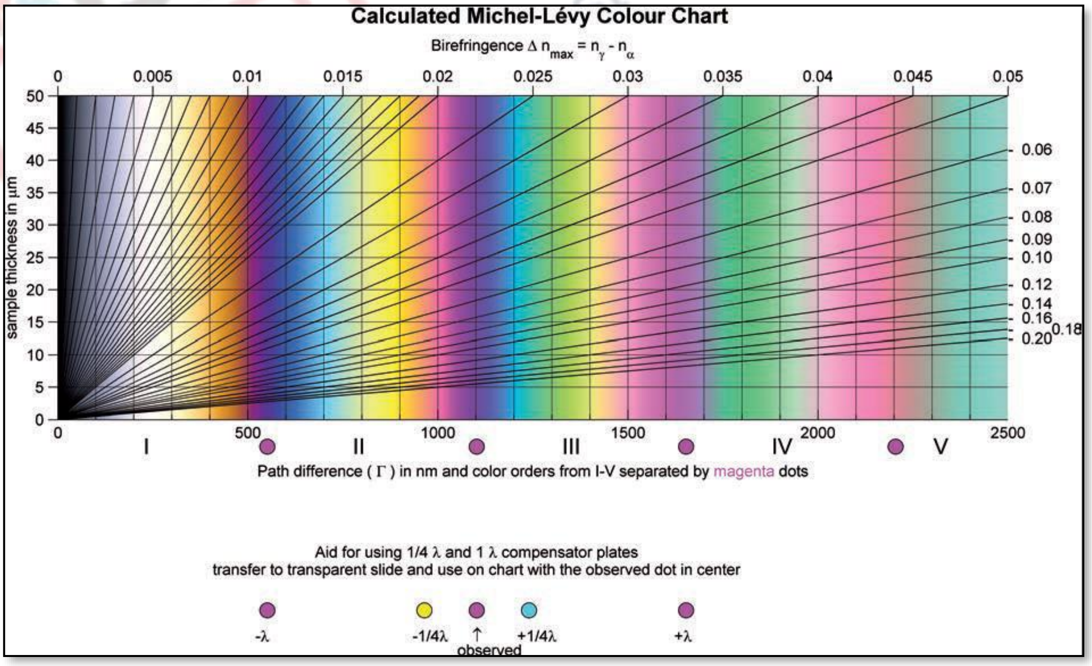

Fig. 5 Michel-Levy chart. Markers for use of 1-lambda and ¼-lambda plates added (After Sorensen, 2013).

The primary function of the interference colour chart is to allow rapid determination of the retardation between the slow and fast rays. Retardation is determined by directly observing the interference colour produced by a mineral grain in thin section and by finding the same color on the colour chart. The numerical value of retardation is read from the bottom of the chart beneath the colour.

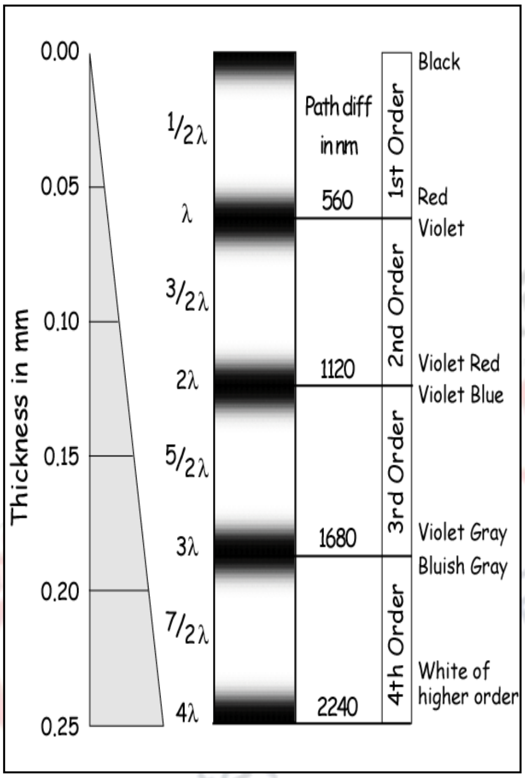

Figure 6. The repeating sequence of colours changes from red to blue at retardations of 550, 1100, and 1650 nm. These boundaries separate the colour sequence into first, second and third order colours. Above fourth order, retardation > 2200 nm, the colours are washed out and become creamy white

If retardation is known for a mineral, it can be used to determine the thickness of a thin section with known birefringence or can be used to determine birefringence of an unknown mineral if thickness is known.

Usually we follow the 655nm line of the path difference across to find the intersection with the corresponding thickness line (usually 25–30μm). From this intersection, follow the "sun line" downwards towards the bottom right to pinpoint the respective birefringence magnitude on the scale on the right.

5. Summary

If two beams of polarized light pass through a crystal, they travel at different speeds and get out of phase. The slow ray is said to be retarded and the phase difference is called *retardation.* If the retardation is a whole number of wavelengths, the beams recombine with the same orientation as when they entered the crystal. These wavelengths will be blocked by the upper polarizer if the retardation is a whole number of wavelengths *plus one-half*; the beams recombine with an orientation perpendicular to the original direction of polarization. These wavelengths will be fully transmitted by the upper polarizer.

The interference colour is the result of a retardation between the waves which are vibrating inside the mineral and is defined by the equation: $\mathbf{\Delta = d(n_S - n_F)}$ where "Δ" represents the retardation, "d" is the thickness of the mineral, and "n_S" and "n_F" are the refractive indices of the waves. This equation has been solved graphically in the chromatic scale of Michel-Levy. This is an extremely useful chart for calculating the birefringence of the minerals from their interference colour. The greater the difference between the indices of refraction, the more intense are the interference colors produced. The difference in the index of refraction in two viewing directions is called the birefringence.

Frequently Asked Questions-

Q1. What is interference colour of a mineral?

Ans. The colour perceived by us when a mineral grain is observed between cross polarizers is called Interference colour. It results due to light being split into two rays on passing through anisotropic mineral with different electronic environment, which varies with direction.

Q2. Describe the phenomena of retardation?

Ans. When plane polarized light enters an anisotropic mineral it is split into fast and slow rays. These rays vibrate at right angle to each other and their total energy is equal to the energy of the incident ray. Both rays travel through the mineral with the fast ray exiting the mineral earlier than the slow ray. The amount that the slow ray lags behind the fast ray upon exiting from the mineral is called as retardation.

Q3. Define Birefringence?

Ans. Birefringence is defined as the double refraction of light in a transparent, molecularly ordered material, which is manifested by the existence of orientation-dependent differences in refractive index.

Multiple Choice Questions-

1. Double refraction is shown by

(a) Isotropic mineral
(b) Uniaxial mineral
(c) Uniaxial and Biaxial mineral

Ans: c

2. Commonly occurring carbonate mineral showing double refraction is

(a) Calcite
(b) Magnesite
(c) Siderite

Ans: a

3. Retardation is denoted by

(a) $\Delta = d(n_S - n_F)$
(b) $\Delta = d(n_S + n_F)$
(c) $\Delta = d/(n_S - n_F)$

Ans: a

4. Birefringence is difference of

(a) Distance travelled by slow and fast ray
(b) Refractive index of slow and fast ray
(c) Difference of velocity of X and Y vibration direction

Ans: b

5. For a two light waves to interfere constructively the path difference has to be

(a) Zero
(b) Multiple of $i\lambda$
(c) Multiple of $(i+1/2\lambda)$

Ans: b

Suggested Readings:

1. Bloss, F. Donald (1971). Crystallography and Crystal Chemistry. Holt, Rinehart and Winston, New York. ISBN: 0030851556, 9780030851551.
2. Klien, Cornelis and Dutrow, Barbara, (2008). Manual of Mineral Sciences (Manual of Mineralogy), 23rd Edn. John Wiley & Sons, New York. ISBN: 0471721573, 978-0471721574.
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