Recommended Text:

Lectures;

Bloss - An Introduction to the Methods of Optical Mineralogy

Lab;

Kerr - Optical Mineralogy

These text books are available in the bookstore and will be used in this course

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Supplementary Texts - Available in the Main Library

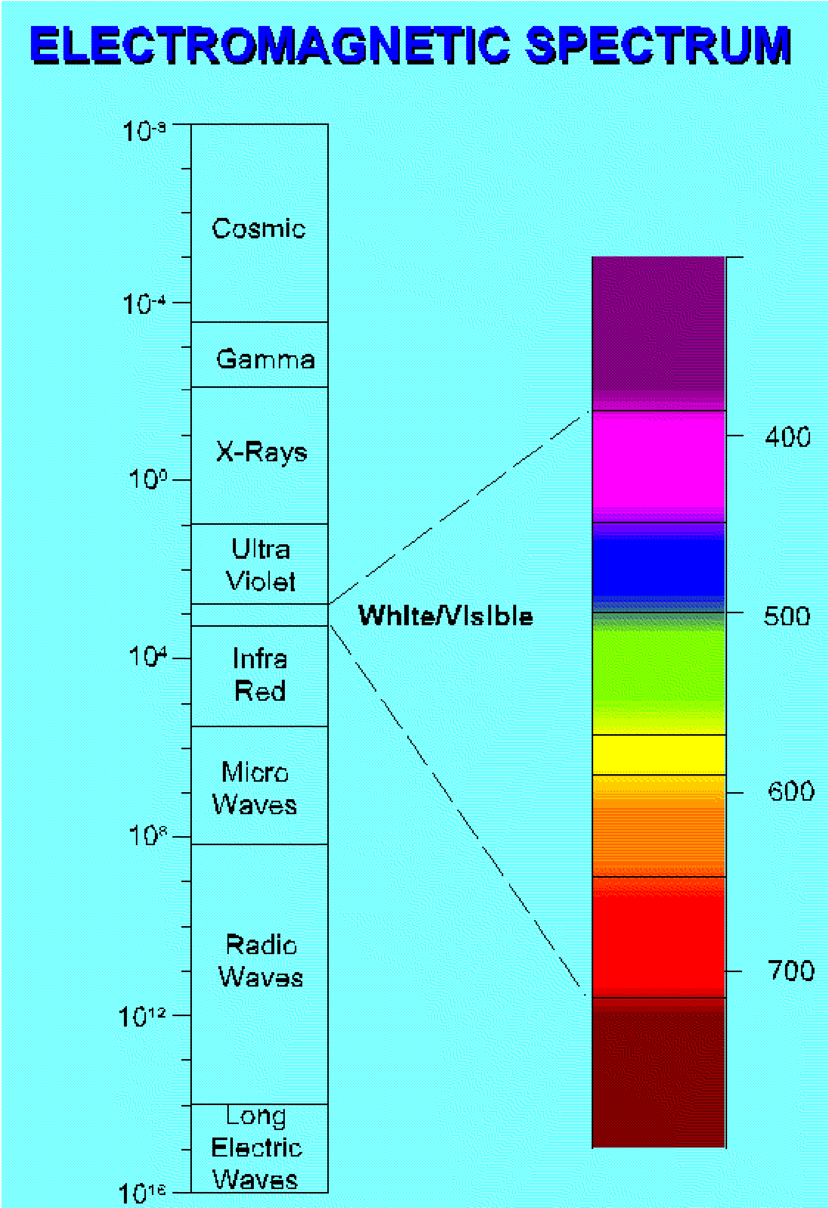
- Introduction to Optical Mineralogy, Third Edition, by William D. Neese
- Phillips - Mineral Optics, Principles and Techniques
- Deer, Howie and Zussman - Rock Forming Minerals. A 7 volume set, invaluable to petrologists.
- Deer, Howie and Zussman - Introduction to Rock Forming Minerals. A condensed version of the 7 volume set.
- Ehlers - Optical Mineralogy Volumes 1 and 2
- MacKenzie and Guilford - Atlas of rock-forming minerals in this section

INTRODUCTION

Light- a form of energy, detectable with the eye, which can be transmitted from one place to another at finite velocity.

Visible light is a small portion of a continuous spectrum of radiation ranging from cosmic rays to radio waves.

Light spectrum



White or visible light, that which the eye detects, is only a fraction of the complete spectrum - produced by shining white light through a glass prism.

Wavelength of visible light

Wavelength (A)	3900-4460	4460-4640	4640-5000	5000-5780	5780-5920	5920-6200	6200-7700
Color	Violet	Indigo	Blue	Green	Yellow	Orange	Red

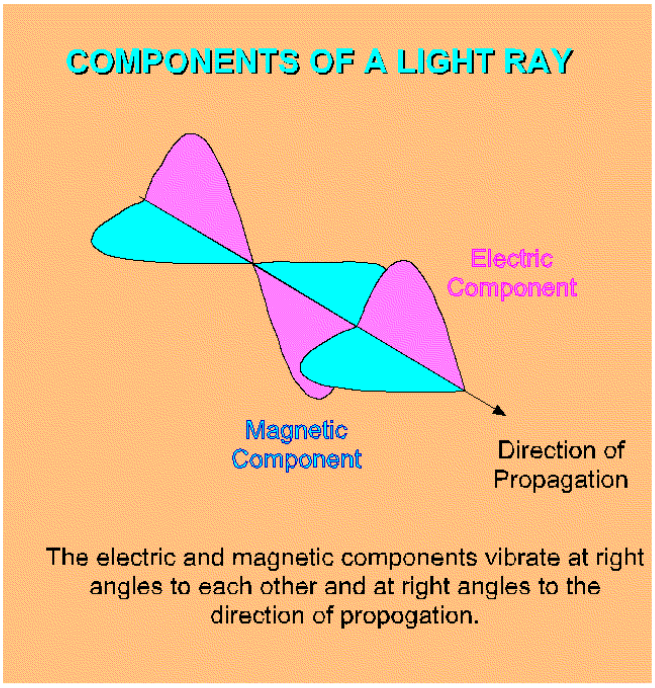
Two complimentary theories have been proposed to explain how light behaves and the form by which it travels.

1. Particle theory - release of a small amount of energy as a photon when an atom is excited.
2. Wave theory - radiant energy travels as a wave from one point to another.

Waves have electrical and magnetic properties => electromagnetic variations.

Wave theory effectively describes the phenomena of polarization, reflection, refraction and interference, which form the basis for optical mineralogy.

Components of a Light Ray



ELECTROMAGNETIC RADIATION

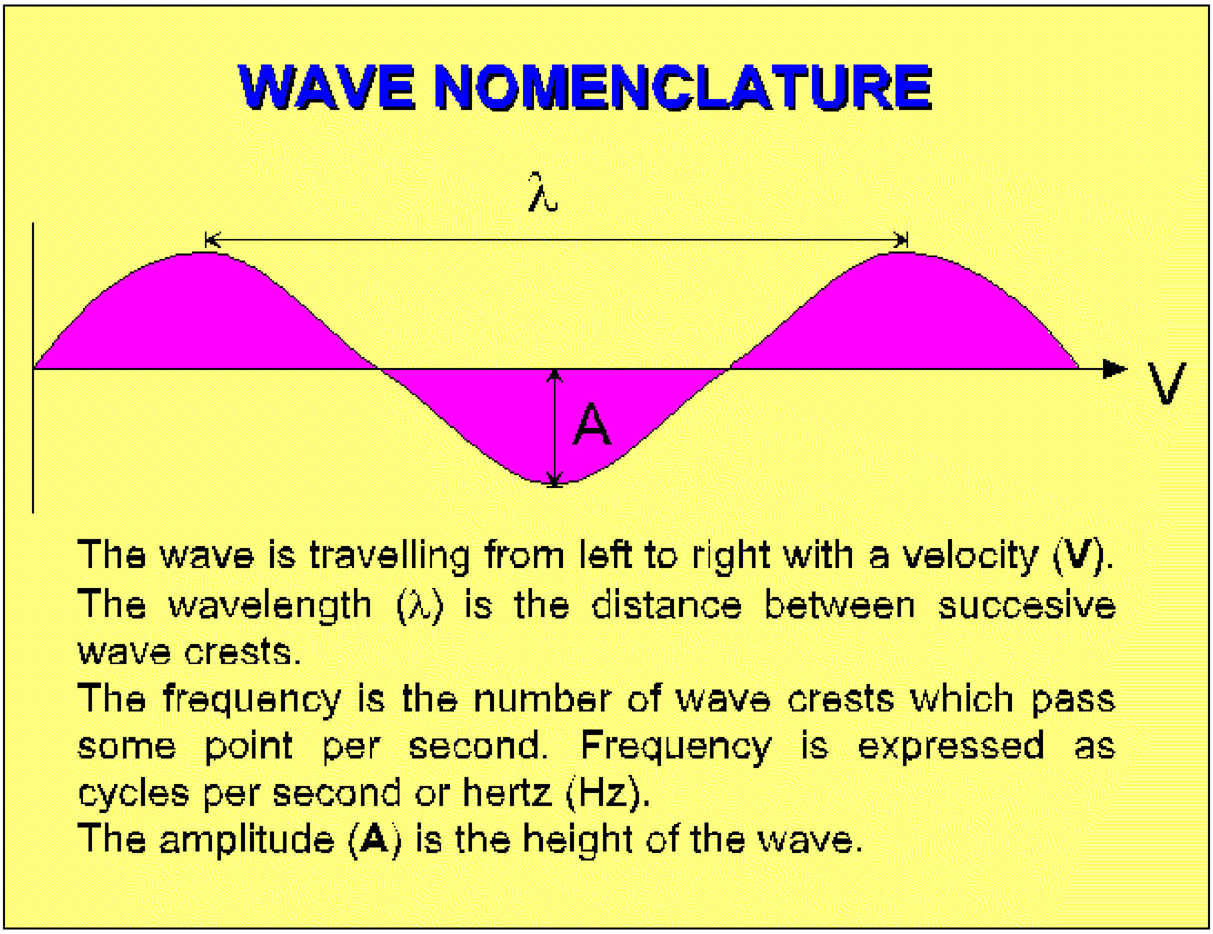
The electromagnetic radiation theory of light implies that light consists of electric and magnetic components which vibrate at right angles to the direction of propagation.

In optical mineralogy only the electric component, referred to as the electric vector, is considered and is referred to as the **vibration direction** of the light ray.

The vibration direction of the electric vector is perpendicular to the direction in which the light is propagating.

The behavior of light within minerals results from the interaction of the electric vector of the light ray with the electric character of the mineral, which is a reflection of the atoms and the chemical bonds within that minerals.

Light waves are described in terms of velocity, frequency and wavelength.



The velocity (V) and the wavelength are related in the following equation

$$F = \frac{V}{\lambda} \qquad \text{Eq.........1-1}$$

where:

F = Frequency or number of wave crests per second which pass a reference points => cycles/second of Hertz (Hz).

For the purposes of optical mineralogy, F = constant, regardless of the material through which the light travels. If velocity changes, then the wavelength must change to maintain constant F.

Light does not consist of a single wave => infinite number of waves which travel together

Refractive index

The index of refraction (n) of a particular material may be defined as

$$n = C/C_m \qquad \text{Eq............1-2}$$

Where C and Cm symbolize the velocity of light in a vacuum and in the material, respectively. For most materials, Cm is less than C ; consequently, refractive index are generally greater than 1.0 in value. Air, through which light travels almost as fast as in a vacuum, has an index of refraction that may be assumed equal 1.0 in most cases. In general, the higher the density of substance, the less rapidly light travels through it.High specific gravity and high refractive index are therefore related physical properties.

The wavelength of light entering a new medium changes inversely proportionally to its refractive index in the new medium. Thus

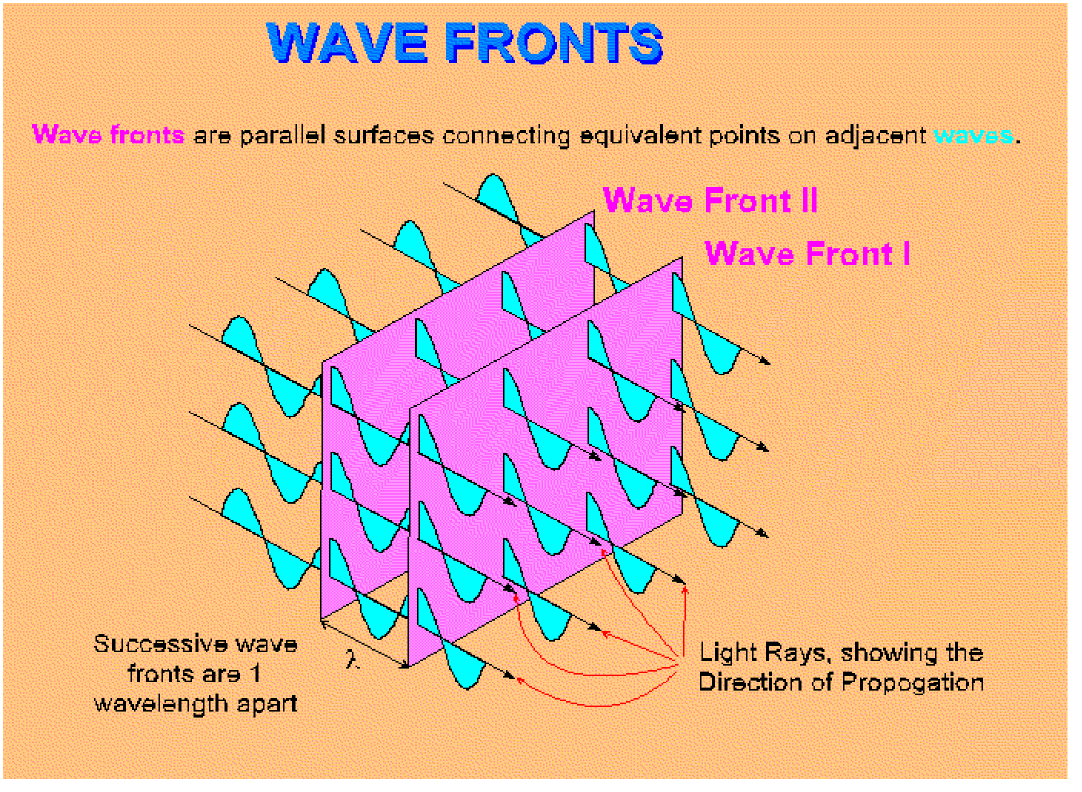
$$\lambda A/ \lambda B = nB/nA \qquad \text{Eq..............1-3}$$

Where nB and nA refer to the refractive index of the two media involved, λA and λB Wave length of light in two media. The derivation of Eq. 1-3 is left to the reader.

WAVE FRONT, WAVE NORMAL

With an infinite number of waves traveling together from a light source, we now define:

1. Wave front - parallel surface connecting similar or equivalent points on adjacent waves.
2. Wave Normal - a line perpendicular to the wave front, representing the direction the wave is moving.
3. Light Ray is the direction of propagation of the light energy.



Minerals can be subdivided, based on the interaction of the light ray traveling through the mineral and the nature of the chemical bonds holding the mineral together, into two classes:

1. Isotropic Minerals

Isotropic materials show the same velocity of light in all directions because the chemical bonds holding the minerals together are the same in all directions, so light travels at the same velocity in all directions.

- Examples of isotropic material are volcanic glass and isometric minerals (cubic) Fluorite, Garnet, Halite

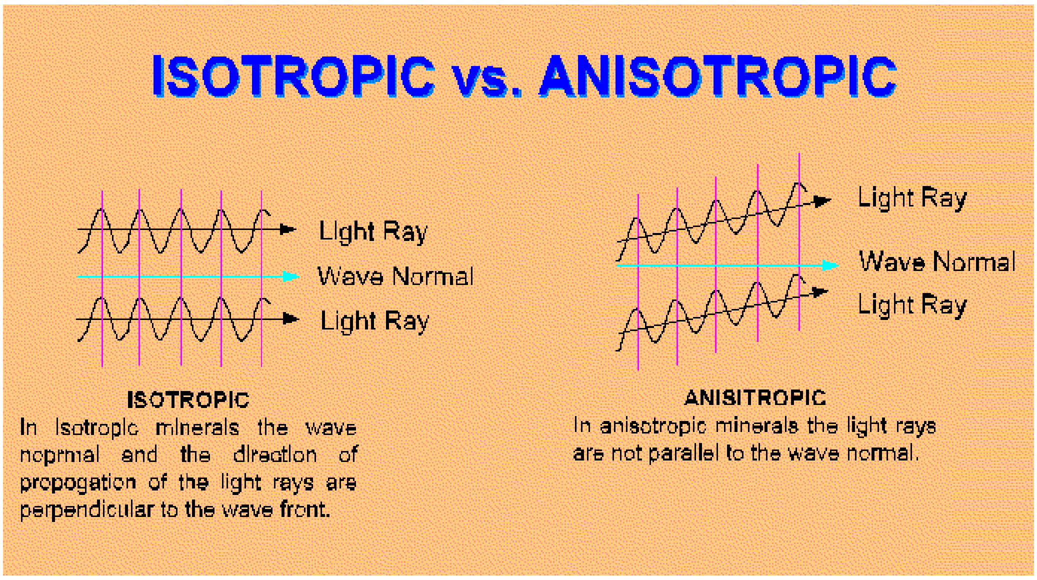
In isotropic materials the Wave Normal and Light Ray are parallel.

2. Anisotropic Minerals

Anisotropic minerals have a different velocity for light, depending on the direction the light is traveling through the mineral. The chemical bonds holding the mineral together will differ depending on the direction the light ray travels through the mineral.

- Anisotropic minerals belong to tetragonal, hexagonal, orthorhombic, monoclinic and triclinic systems.

In anisotropic minerals the Wave Normal and Light Ray are not parallel.

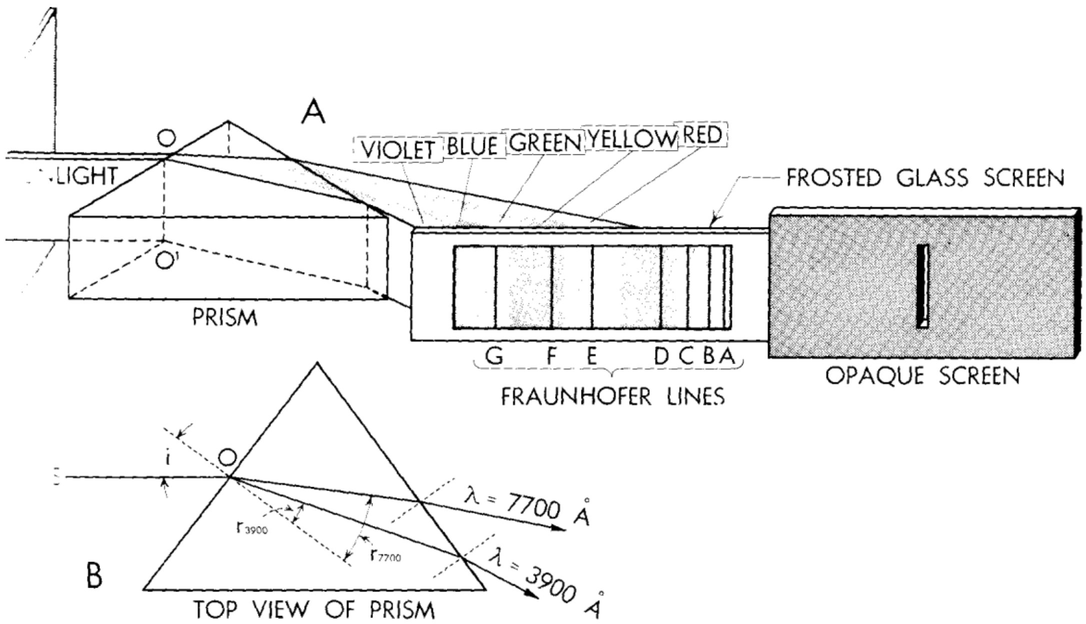


Light waves traveling along the same path in the same plane will interfere with each other.

Dispersion of sunlight

Assume that a glass prism has indices of refraction of 1.600 and 1.500 for light of wavelengths 3900 A and 7700 A, respectively. If, as in Fig. 2-4A, this prism is arranged with its vertical edge parallel to the slit, SS', only a very narrow beam of sunlight would impinge upon the prism. The same angle

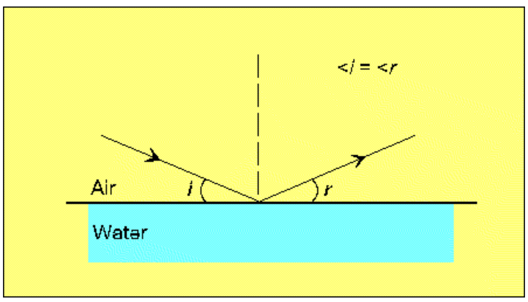
^ OPAQUE SCREEN



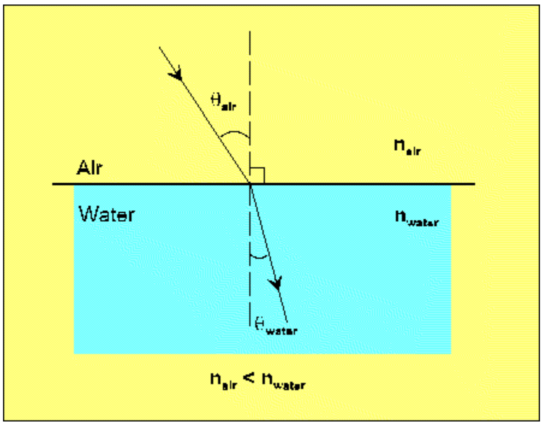
FIG(2-4)A- Prism dispersing sunlight from slit SS'. Dark lines A to G in the resulting spectrum are the Fraunhofer lines. Note (hat if the opaque screen is slid toward the left. its slit would isolate monochromatic light of a relatively narrow ranging in wavelength. (B) Top view of prism. Note that two different angles of refraction, r3900 and r7700, result from the same angle of incidence

REFLECTION AND REFRACTION

At the interface between the two materials, e.g. air and water, light may be reflected at the interface or refracted (bent) into the new medium.



For **Reflection** the angle of incidence = angle of reflection.



For **Refraction** the light is bent when passing from one material to another, at an angle other than perpendicular.

A measure of how effective a material is in bending light is called the **Index of Refraction (n)**, where:

$$n = \frac{V_{Vac}}{V_{Mat}}$$

Index of Refraction in Vacuum = 1 and for all other materials n > 1.0.

Most minerals have n values in the range 1.4 to 2.0.

A high Refractive Index indicates a low velocity for light travelling through that particular medium.

Snell's Law :

Two parallel light are refracted across an interference between two nonopaque media.The line AB represents the velocity of ray 1 and CD represents the velocity of ray 2. The angle of incidence i, shown at point D is equivalent to angleBAD of refraction r shown at point D is equivalent to angle ADC

Sin i = BD/AD and sin r =AC/AD

Then sin i/ sinr =BD/ AC

Recalling that BD=v1 and AC= v2

Then sini /sinr = v1/v2

As n1= v vacuum / v1 and n2= v vacuum/ v2

Subsititution results in the following general version of Snell's Law :

Sini /sinr= n2/n1

If the material 1 is a vacuum or air, such that n1 is 1 then

Sini /sinr=n2

$$\frac{\sin \theta_{air}}{\sin \theta_{water}} = \frac{n_{water}}{n_{air}}$$

Snell's law can be used to calculate how much the light will bend on travelling into the new medium.

If the interface between the two materials represents the boundary between air (n ~ 1) and water (n = 1.33) and if angle of incidence = 45°, using Snell's Law the angle of refraction = 32°.

The equation holds whether light travels from air to water, or water to air.

In general, the light is refracted towards the normal to the boundary on entering the material with a higher refractive index and is refracted away from the normal on entering the material with lower refractive index.

In labs, you will be examining refraction and actually determine the refractive index of various materials.

POLARIZATION OF LIGHT

All of this introductory material on light and its behaviour brings us to the most critical aspect of optical mineralogy - that of **Polarization of Light**.

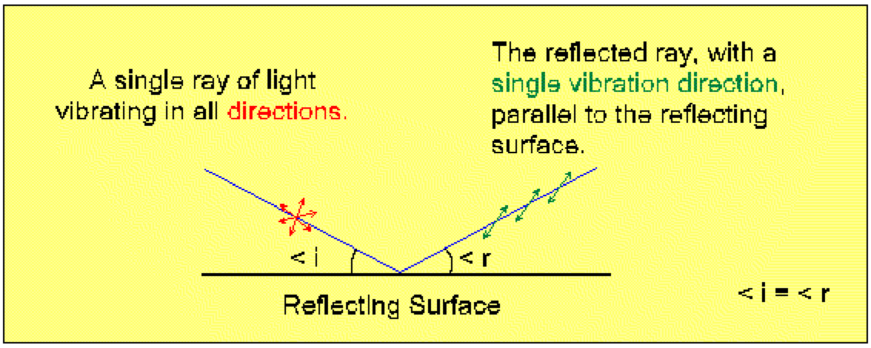
Light emanating from some source, sun, or a light bulb, vibrates in all directions at right angles to the direction of propagation and is unpolarized.

In optical mineralogy we need to produce light which vibrates in a single direction and we need to know the vibration direction of the light ray. These two requirements can be easily met but polarizing the light coming from the light source, by means of a polarizing filter.

Three types of polarization are possible.

1. Plane Polarization
2. Circular Polarization
3. Elliptical Polarization

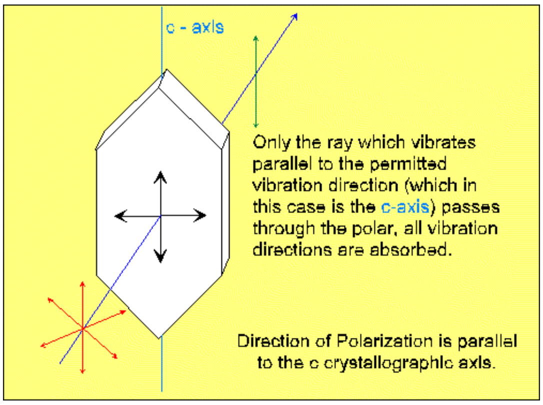
1. Reflection



Unpolarized light strikes a smooth surface, such as a pane of glass, tabletop, and the reflected light is polarized such that its vibration direction is parallel to the reflecting surface.

The reflected light is completely polarized only when the angle between the reflected and the refracted ray = 90°.

2. Selective Absorption



This method is used to produce plane polarized light in microscopes, using polarized filters.

Some anisotropic materials have the ability to strongly absorb light vibrating in one direction and transmitting light vibrating at right angles more easily. The ability to selectively transmit and absorb light is termed pleochroism, seen in minerals such as tourmaline, biotite, hornblende, (most amphiboles), some pyroxenes.

Upon entering an anisotropic material, unpolarized light is split into two plane polarized rays whose vibratioin directions are perpendicular to each other, with each ray having about half the total light energy.

If anisotropic material is thick enough and strongly pleochroic, one ray is completely absorbed, the other ray passes through the material to emerge and retain its polarization.

3. Double Refraction

This method of producing plane polarized light was employed prior to selective absorption in microscopes. The most common method used was the Nicol Prism.

Calcite experiment and double refraction

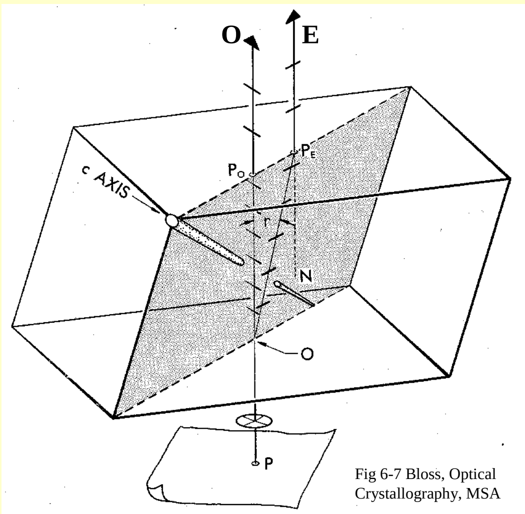


Fig 6-7 Bloss, Optical Crystallography, MSA

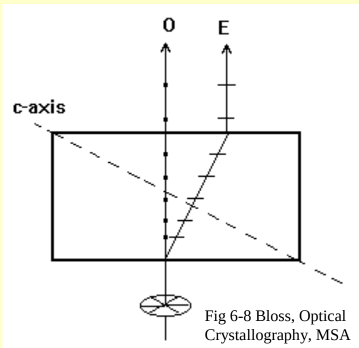


Fig 6-8 Bloss, Optical Crystallography, MSA