Properties of Light I

Light – definition

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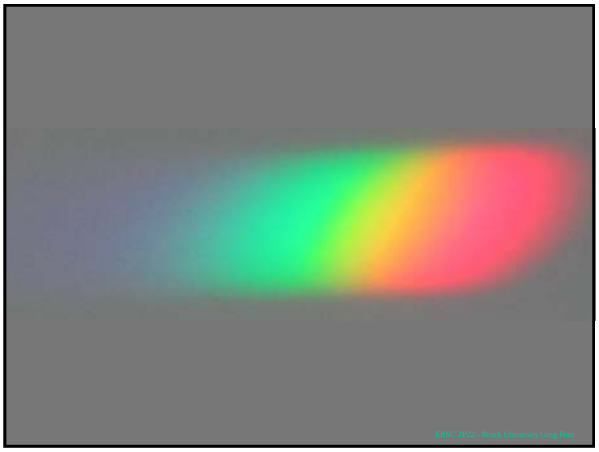
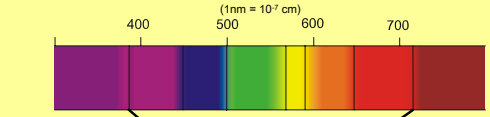
- –
- –
- –



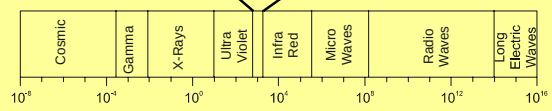
Light Spectrum

Wavelength in nm

(1nm = 10^{-7} cm)



Visible/White Light



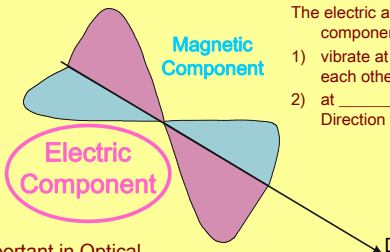
Theory of Light

- Two complimentary theories to explain how light behaves and the form by which it travels:
  - Particle Theory
    - _____
  - Wave Theory
    - _____
    - Waves have _____ and _____ properties
      - _____ Radiation

Theory of Light

- Wave theory explains polarization, reflection, refraction and interference
- The basis of Optical Mineralogy

Components of a Light Ray



The electric and magnetic components:

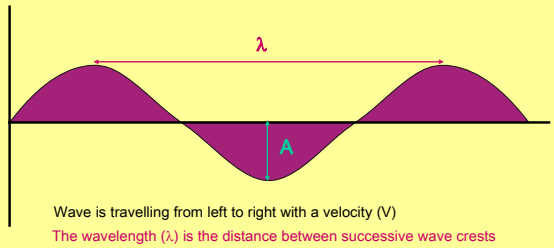
1) vibrate at _____ to each other, and
2) at _____ to the Direction of Propagation

Important in Optical, referred to as the Vibration Direction of the Light Ray

Light

- Behaviour of light in minerals results from the _____ of the Electric Component, or vector, with the electric character of the ____ and the chemical _____ holding the mineral together
- Vibration direction of the electric vector is _____ to the direction of propagation of the light ray

Wave Nomenclature



Wave is travelling from left to right with a velocity (V)

The wavelength (λ) is the distance between successive wave crests

The amplitude (A) is the height of the wave

The frequency is the number of wave crests per second which pass a reference point. Frequency is expressed as cycles per second or Hertz (Hz).

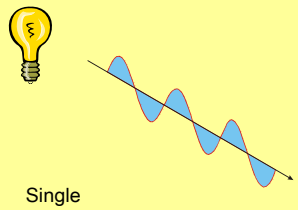
Wave Nomenclature

- Light waves are described in terms of:
  - Velocity (V)
  - Frequency (F)
  - Wavelength (λ), where:

$$F = \frac{V}{\lambda}$$

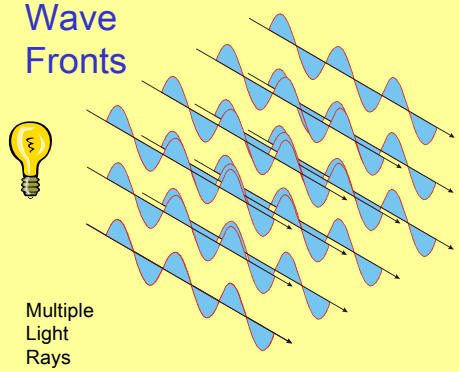
F is a constant and V of λ will vary to maintain F

Wave Fronts



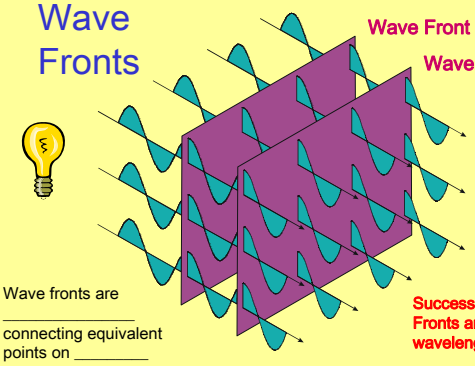
Single Light Ray

Wave Fronts



Multiple Light Rays

Wave Fronts



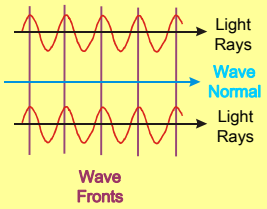
Wave fronts are _____ connecting equivalent points on _____ _____

Successive Wave Fronts are 1 wavelength apart

Isotropic Materials

For Isotropic Materials

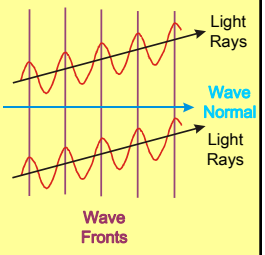
The Wave Normal and the **Direction of Propagation** of the light rays are _____ to each other and _____ to the Wave Front



Anisotropic Materials

For Anisotropic Materials

The Wave Normal and the **Direction of Propagation** of the light rays _____.



Isotropic vs. Anisitropic

- Shows same velocity of light in all directions
- Bonds are the same in all directions
- Wave Normal and Direction of Propagation are parallel
- Isometric minerals and volcanic glass

- Different velocity for light with direction
- Bonds differ with direction
- Wave Normal and Direction of Propagation are not parallel
- Tetragonal, hexagonal, orthorhombic, monoclinic and triclinic systems

Properties of Light II

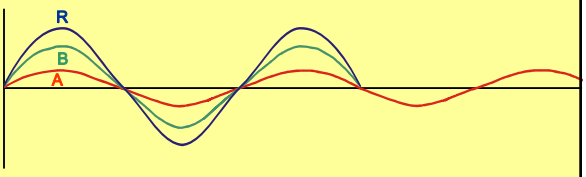
Continued

Phase and Interference

- Light rays travelling along the same path in the same direction will _____ with each other
- **RETARDATION (Δ)**
  - Represents the distance that one ray lags behind another
  - Measured in nanometres (μm; 1μm = 10^{-7} cm) **OR** the number of wavelengths by which a wave lags behind another

Phase and Interference

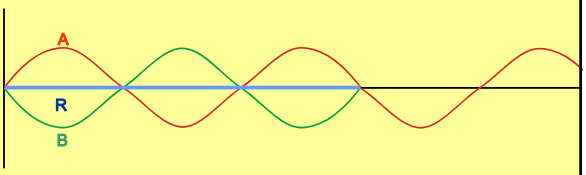
Δ = 1, 2, 3 … wavelengths



Waves A and B are _____ (Δ = 1λ), so that the waves constructively interfere and produce the resultant wave (R)

Phase and Interference

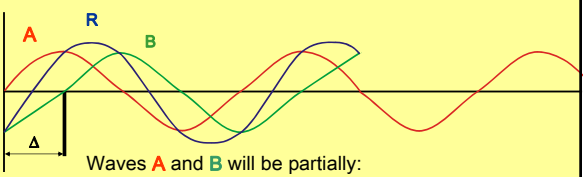
Δ = ½, 1 ½, 2 ½ … Wavelengths



Waves A and B are _____ (Δ = (i + ½λ)). The amplitudes of waves A and B are equal, but opposite, they cancel each other (destructive interference) and the resultant wave (R) has zero amplitude.

Phase and Interference

Δ = Intermediate Number of Wavelengths



Waves A and B will be partially:

1) **IN PHASE**, with the interference being partially constructive, and;

2) **OUT OF PHASE** with the interference being partially destructive.

The resultant wave (R) is the sum of the two waves

Phase and Interference

- In the previous examples the rays were vibrating in the same plane
  (This makes the visualization simpler)
- If the two rays vibrate at some angle to each other they will still interfere and produce a resultant wave, whose vibration direction can be determined mathematically

Perception of Colour

- Human eye can discriminate different wavelengths of light – why we see colours
  – Red light has a wavelength of 660 nm
- Light of all one wavelength is termed _____ light and is perceived as the colour associated with that wavelength

Perception of Colour

- Light of more than one wavelength is termed _____ light
- When all of the visible spectrum is present we 'see' _____ _____
- The colour that we perceive results from a combination of wavelengths being _____/_____ by the material

Interaction of Light and Matter

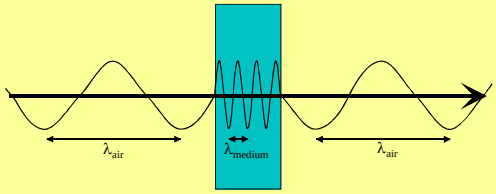
Transmitted Light

- In a vacuum light travels at 3 X 10^{10}cm/sec (3 X 10^{17}nm/sec)
- In any other medium (minerals) it is _____ down, due to the interaction of the electric vector of the light with the electronic configuration of the mineral
- To maintain a constant frequency, the _____ of light must also change:

$$F = \frac{v}{\lambda}$$

Transmitted Light

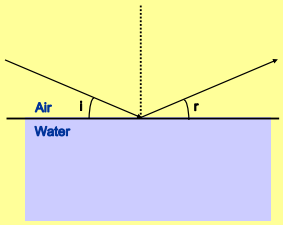
- Light is slowed (velocity drops) when it enters another medium. To maintain F, as a constant, the wavelength must shorten as well.



Transmitted Light

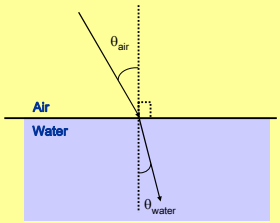
- When a light ray strikes the boundary between two substances at an oblique angle the light may be:
  –
  –
  –

Reflection



angle of incidence = angle of reflection
<i = <r

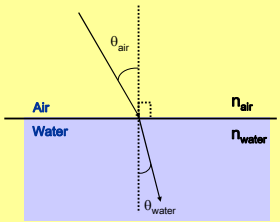
Refraction



Refraction of Light

From: http://hyperphysics.phy-astr.gsu.edu/hbase/geoopt/optpic/brokpen.jpg

Refraction



A measure of how effective a material is at bending light is termed the _____ (n)

Index of Refraction

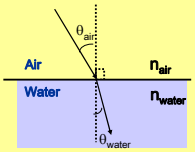
- Index of Refraction – **n**

  $n = V_{vac}/V_{medium}$
- Most minerals have **n** values in the range 1.4 to 2.0
- A _____ **n** or **RI** indicates a ___ velocity for light in that medium
- A ____ **n** or **RI** indicates a ____ velocity for light in that medium

How much will light bend?

- Use Snell's Law

$$\frac{\sin\theta_a}{\sin\theta_w} = \frac{n_w}{n_a}$$



- $n_a = n_{vac} = 1$, $n_w = 1.33$
- If $\theta_a = 45°$
- Then $\theta_w = 32°$
- Equation holds for either direction

Light Absorption and Colour

- The colour of a mineral is the colour of light that is _____ absorbed on transmission or reflection
  - A white object looks white because it reflects essentially all the visible light spectrum
  - A black object absorbs all wavelengths of light
  - A clear mineral transmits essentially all the visible spectrum
  - A mineral is coloured because it selectively absorbs certain wavelengths of light and transmits or reflects the remaining light to your eye

Light Absorption and Colour

- The perceived colour is dependant on which _____ are transmitted to the eye, and how the eye interprets these wavelengths
- The perceived colour of a mineral is dependant on the colour of the _____ light
- An object that is white in sunlight, will appear blue in blue light, red in red light, etc. as these are the only wavelengths of light transmitted to the observer

Light Absorption and Colour

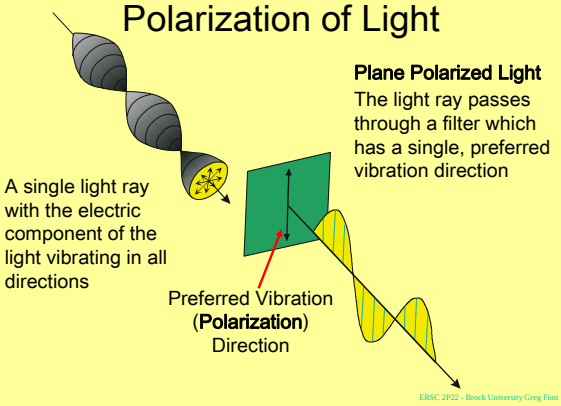
- At the atomic scale, the colors of light absorbed by a mineral are dependant on the _____ between the _____ vector of the light and the natural resonances of the _____ around each atom
  - If the frequency of light is different than the natural resonance, then the light is transmitted
  - If the frequency of light is nearly the same as the natural resonance than the light is absorbed

Polarization of Light

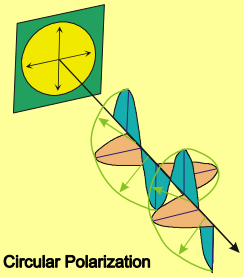
- All this introductory material on the nature and behaviour of light brings us to the most critical aspect of optical mineralogy:

_____

Polarization of Light



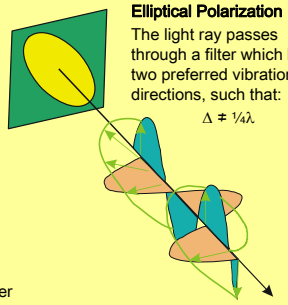
Polarization of Light



Circular Polarization

The light ray passes through a filter which has two preferred vibration directions, such that:

$\Delta = \frac{1}{4}\lambda$



Elliptical Polarization

The light ray passes through a filter which has two preferred vibration directions, such that:

$\Delta \neq \frac{1}{4}\lambda$

Polarization by Reflection

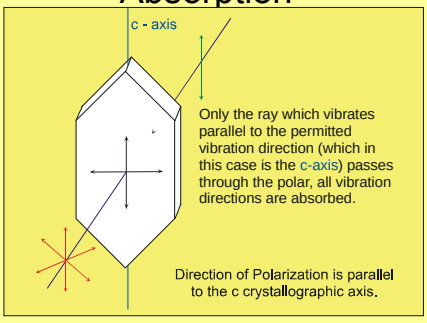
A single ray of light vibrating in all directions.

The reflected ray, with a single vibration direction, parallel to the reflecting surface.

< i = < r

Reflected light is completely polarized only when the angle between the reflected and the refracted ray is 90°

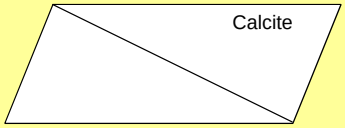
Polarization by Selective Absorption



Only the ray which vibrates parallel to the permitted vibration direction (which in this case is the c-axis) passes through the polar, all vibration directions are absorbed.

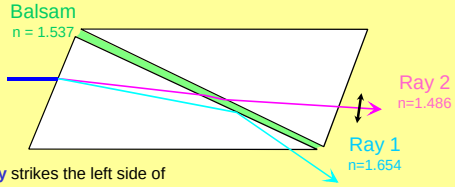
Direction of Polarization is parallel to the c crystallographic axis.

Polarization by Double Refraction via Nicol Prism



The Nicol Prism – constructed of calcite, first must cut the calcite on the diagonal, and then glue the two pieces back together with Balsam (n=1.537).

Polarization by Double Refraction



A **light ray** strikes the left side of the calcite and is split into two rays – **Ray 1** and **Ray 2**, each with different refractive indices. **Ray 1** undergoes total internal reflection when it reaches the **Balsam**, because the angle of incidence is greater than the critical angle.

Ray 2 passes through the first piece of calcite into the **Balsam** and then into the second piece of calcite, being refracted at each interface and retains its polarization direction upon exiting the calcite.