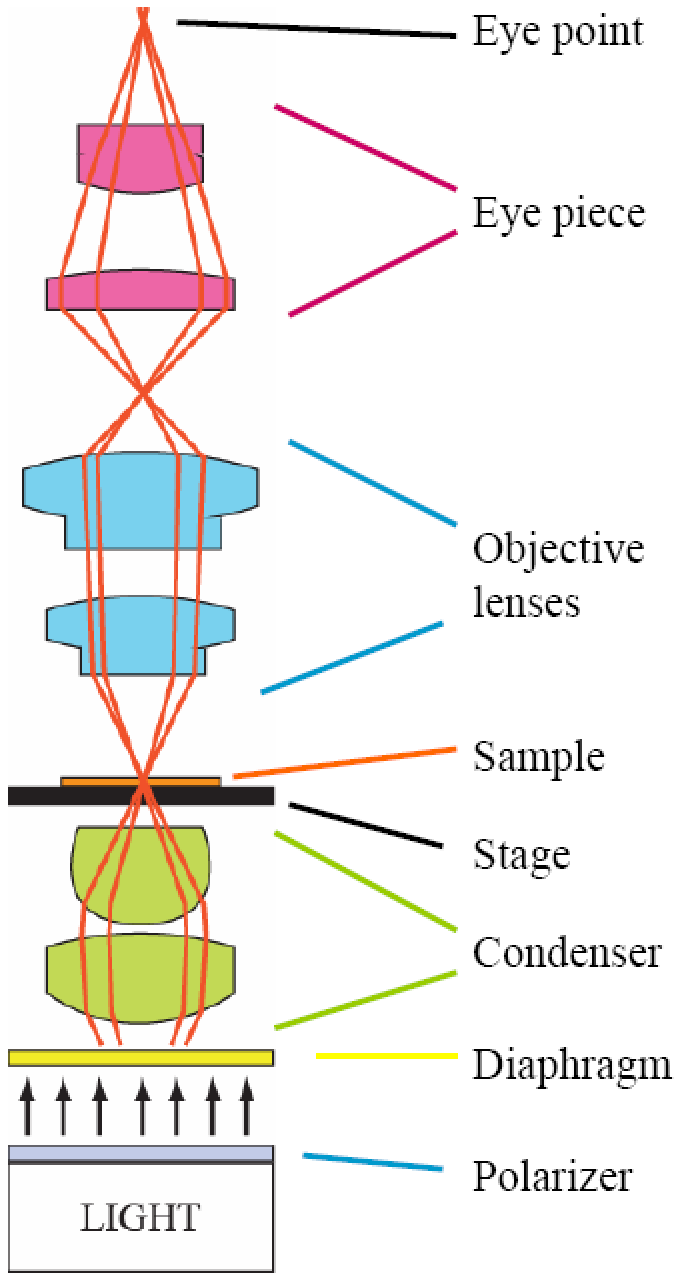
Crystal Optics of Visible Light

This can be a very helpful aspect of minerals in understanding the petrographic history of a rock. The manner by which light is transferred through a mineral is a means to describe and quantify mineral properties **in situ** as well as to describe the relationships between minerals in a rock.

The interaction and behavior of light within minerals is a key diagnostic features that can be applied in multiple ways.

To study minerals in thin section we use a polarizing light microscope or petrographic microscope

Using a substage light source with a series of lenses, polarizer(s), and light intensity adjustments we can examine the properties of a mineral

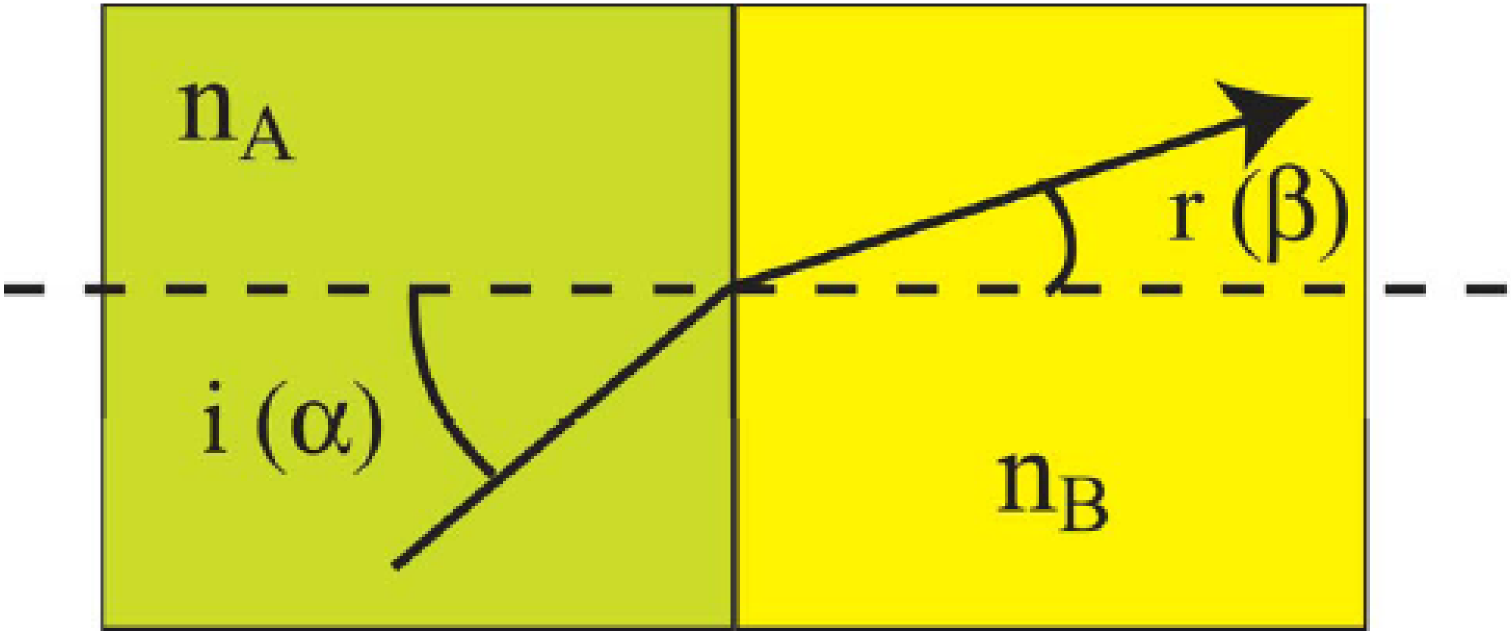


The path of light in a polarizing microscope

The vernier graduated stage on a petrographic microscope can be freely rotated through 360°

There are two condensers that can be used to vary the diameter of the beam of light interacting with the sample (helpful when using the Bertrand Lens for viewing interference figures)

The substage diaphram is used for altering the light intensity (most useful for viewing relief and observing the Becke Line)

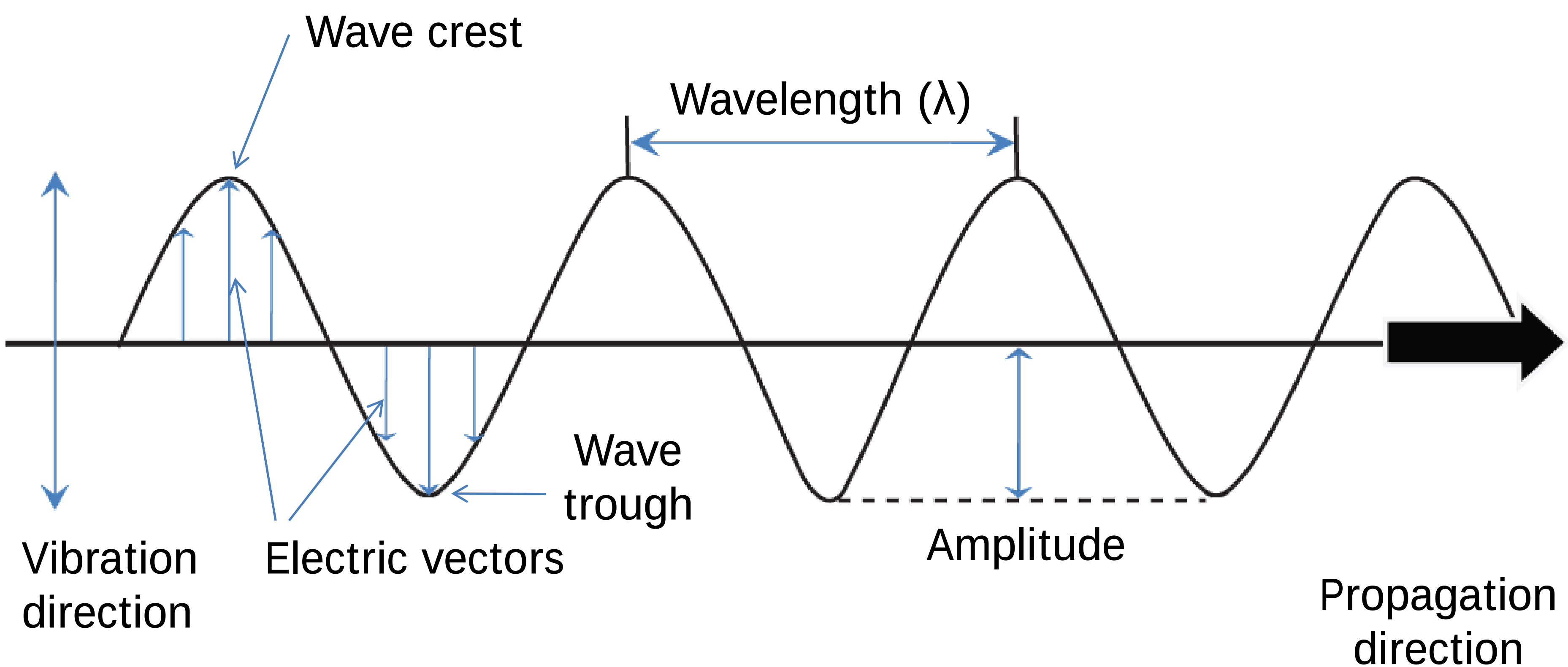


$$\frac{\text{Light velocity in material A}}{\text{Light velocity in material B}} = \frac{\sin \alpha}{\sin \beta}$$

- This is **Snell's Law**: the propagation velocity of light in a medium A to its velocity in a denser medium B is equal to the ratio of the sines of the angle of incidence (α) at the interface and the angle of refraction (β) with B.

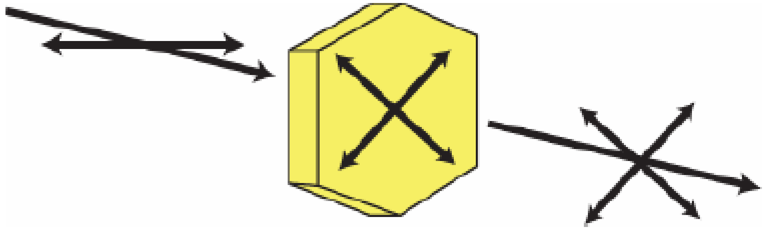
The Wave Theory of Light

This concept is based upon the electromagnetic spectrum and the 400-700 nanometer energy range of visible light humans are capable of seeing

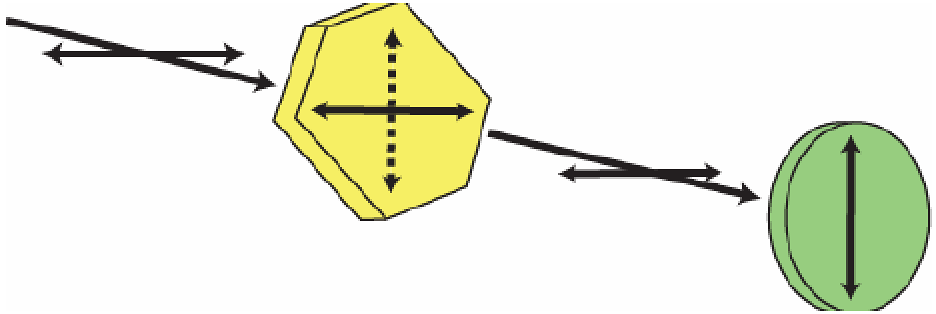


Anisotropic minerals

These are minerals cabable of polarzing into two light rays vibrating perpendicular to each other (double refraction).



Anisotropic minerals are unique in that they can be rotated so that polarizing light is unaffected by the double refraction of the anisotropic minerals



Anisotropic minerals will extinguish four times during a 360° of rotation in cross-polarized light

In anisotropic minerals there is a difference in the rate at which light travels depending on the size of the refractive index

-*n*: direction of the smaller refractive index ~ light moves quickly in this direction

-*N*: direction of the larger refractive index ~ light moves more slowly in this direction

The relationship between *N* and *n* leads to the concepts of *birefringence* and *retardation*

From crystal systems to optical classes

-Based on the axial relationships of our 6 crystal systems, we are able to create three distinct optical groups (2 of which are further subdivided)

-The classes are identified by a surface that is related to the speed of light through a particular crystal, the length of which is proportional to the **refractive index** (*n*)

$$n = \frac{\text{velocity of light in a vacuum}}{\text{velocity of light in a material}}$$

-Velocity of a light wave is determined by the electron density in a material as well as the distribution of the density – the result is that charge distribution has a major affect on the way light is transmitted through a particular medium

-Refractive indices are quite useful in identifying minerals versus liquids of a know index or relative to one another

-With a petrographic microscope, this is done using the ***Becke Line test***:

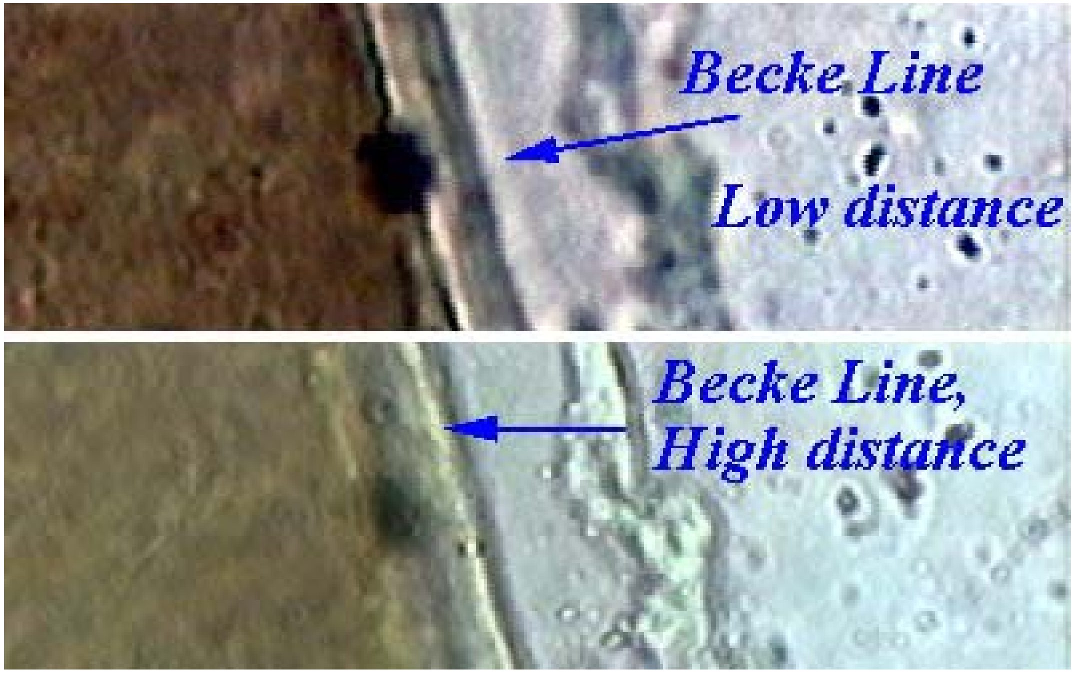
1) Focus a medium to high power on the grain boundaries of the mineral of interest

2) Slowly de-focus the view by *lowering the stage*

3) The grain boundaries will *move into* the medium with the *higher* with the higher refractive index

-The optical relief (or relative height of a mineral) is also a semi-quantitative observational tool that can be used to describe the difference between the refractive indices of two materials

-Materials with a large difference in *n* are “high relief” versus materials with very similar *n* values that are “low relief”



Polarising materials....

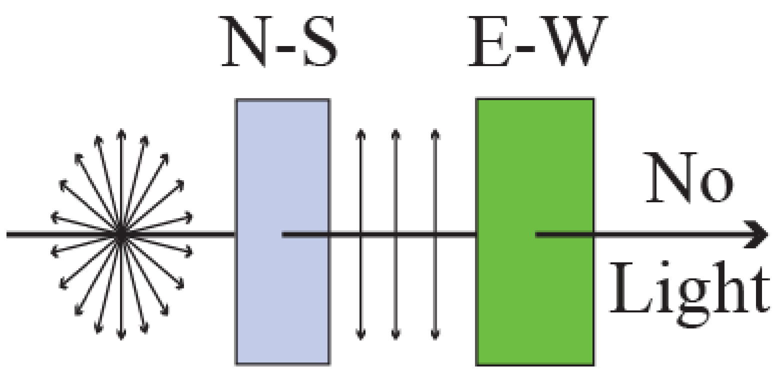
Polaroid

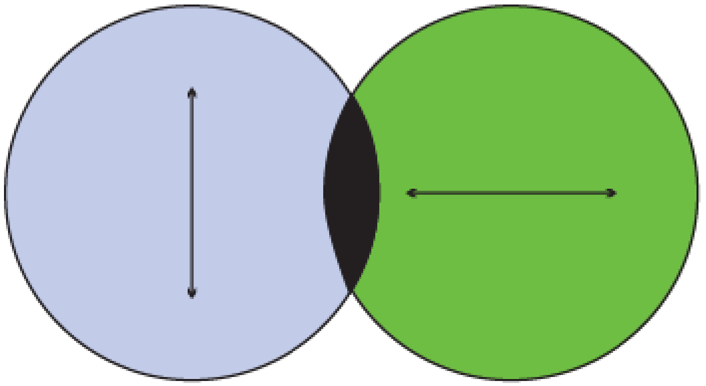
Glass

Minerals (tourmaline)

When two pieces of the polarizing medium are combined placed one upon the other with a 90° offset no light is transmitted.

This is called Crossing the Polarisers





Isotropic Minerals (Cubic Minerals)

When light enters a cubic (isotropic) mineral its vibrational properties are unaffected.

What does this mean?

What does happen to the light?

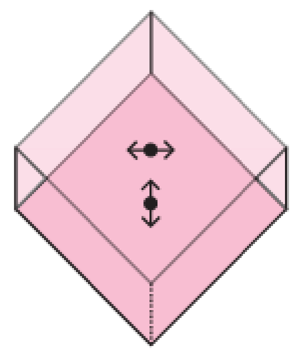
When light passes through such a mineral its vibration direction, produced by the polariser, is not changed.

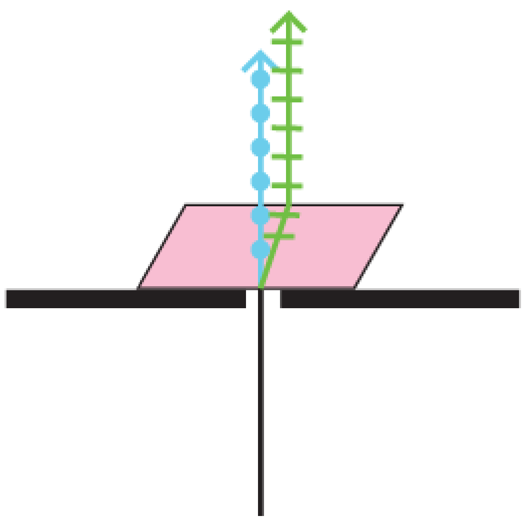
What does this mean when we view such minerals in cross-polarised light?

Double Refraction

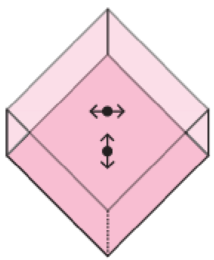
A property of all anisotropic minerals, but spectacularly displayed in calcite.

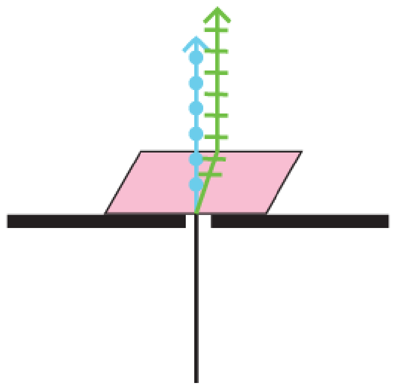
The calcite splits the polarized the light into two perpendicular vectors.





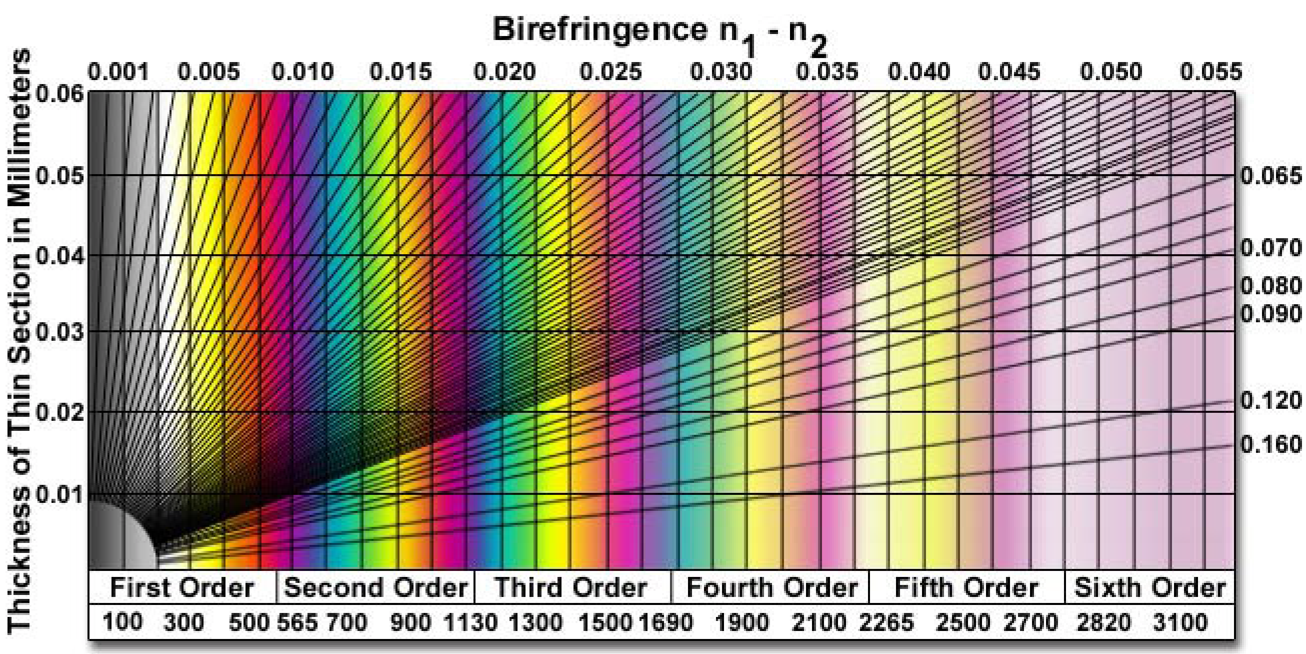
This can be prove with the assistance of a polariser. When the calcite rhomb is oriented in specific directions relative to a polariser one or other of the light-beams is absorbed. When the angle is oblique both spots are seen.



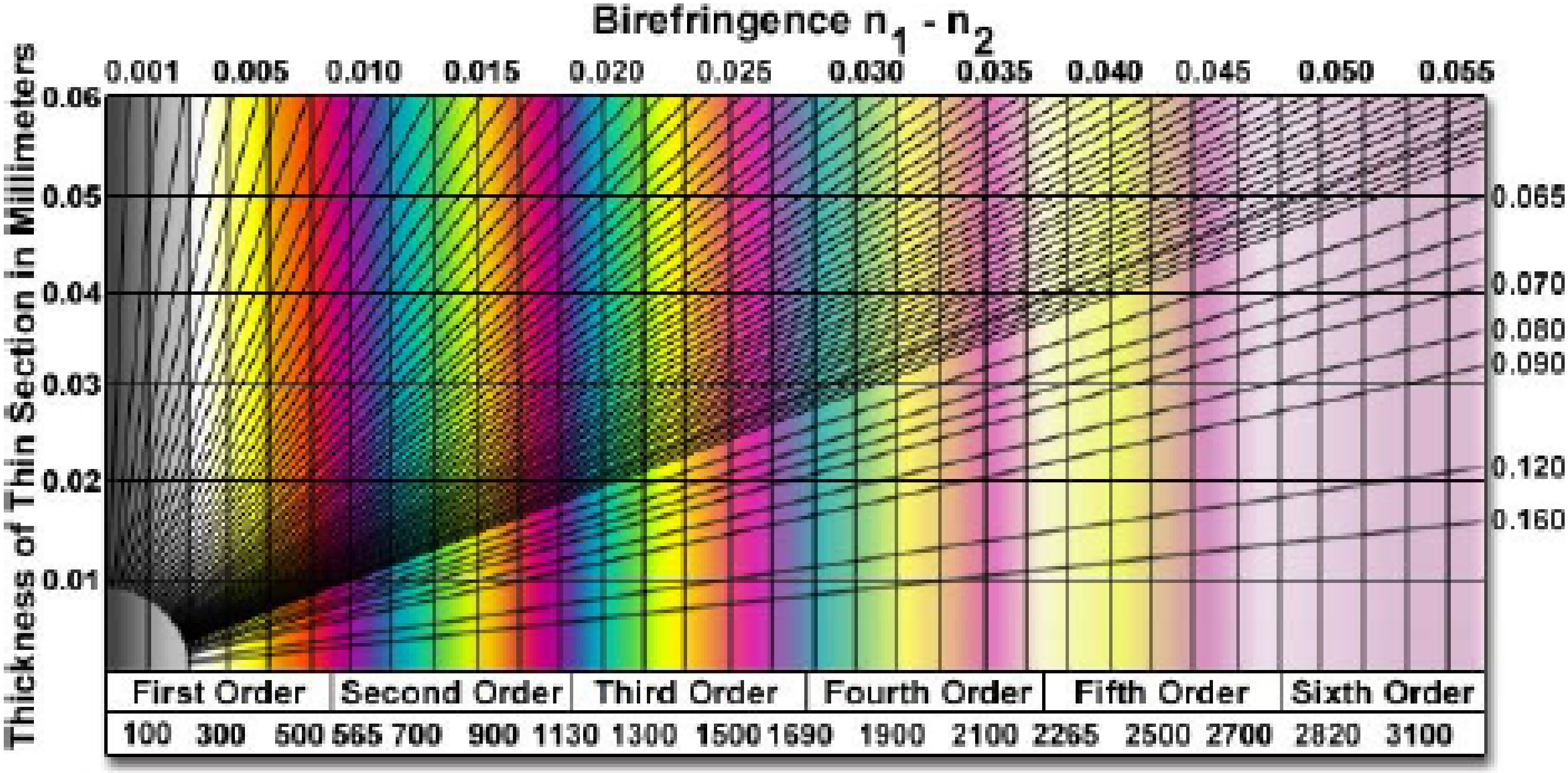


The difference between the largest and smallest possible refractive indice values is called the ***birefringence***.

The ***birefringence*** colour is what is recorded when an anisotropic mineral is viewed in crossed-polarised light.



The interference order is a measure of retardation (path difference).


Birefringence $n_1 - n_2$
0.001
0.005
0.010
0.015
0.020
0.025
0.030
0.035
0.040
0.045
0.050
0.055
Thickness of Thin Section in Millimeters
0.06
0.05
0.04
0.03
0.02
0.01
0.065
0.070
0.080
0.090
0.120
0.160
First Order
Second Order
Third Order
Fourth Order
Fifth Order
Sixth Order
100
300
500
565
700
900
1130
1300
1500
1690
1900
2100
2265
2500
2700
2820
3100

Crystal System	Optical Class	Axes	# of optic axes
Isometric	Isotropic	*n*	Infinite
Tetragonal	Uniaxial	$\varepsilon > \omega$ (+) $\varepsilon < \omega$ (-)	1
Hexagonal			
Orthorhombic	Biaxial	β closer α (+) β closer γ (-)	2
Monoclinic			
Triclinic			

[Isotropic]

Anisotropic

- [Uniaxial positive]
- [Uniaxial negative]
- [Biaxial positive]
- [Biaxial negative]

-Optic axis: perpendicular to the circular direction

-Acute bisectrix (2V): angle less than 90° between 2 optic axes in biaxial minerals

-Obtuse bisectrix: bisects the larger angle in a biaxial mineral

REVIEW
Refractive indices
Becke line
Relief
Birefringence
Polarization of light

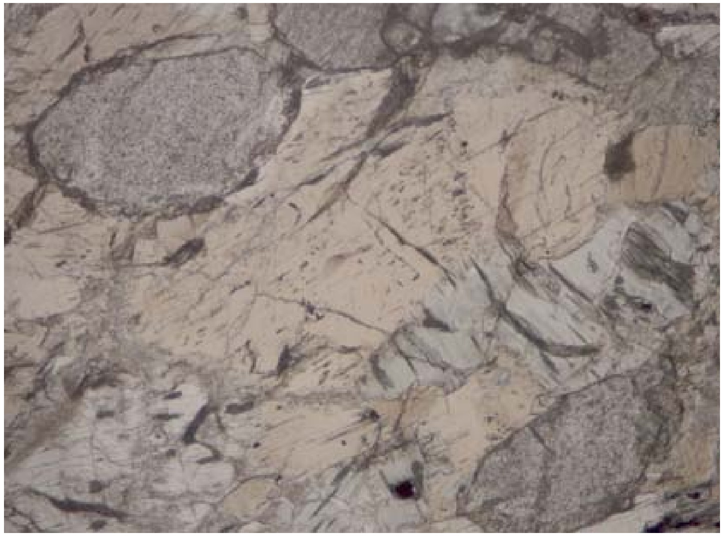
- Geologists use polarising microscopes to study the interaction between light and minerals of interest.
- When light passes between two mediums of differing refractive index (density) its velocity changes (i.e. its speed and direction).
- Light moves away from the norm in lower RI materials.
- When the angle of incidence passes a certain point all light is reflected at the interface.
- Our microscopes polarise the light – we use light that only vibrates in one direction.
- Light entering isotropic minerals is unchanged.
- Light entering anisotropic minerals is split in two.

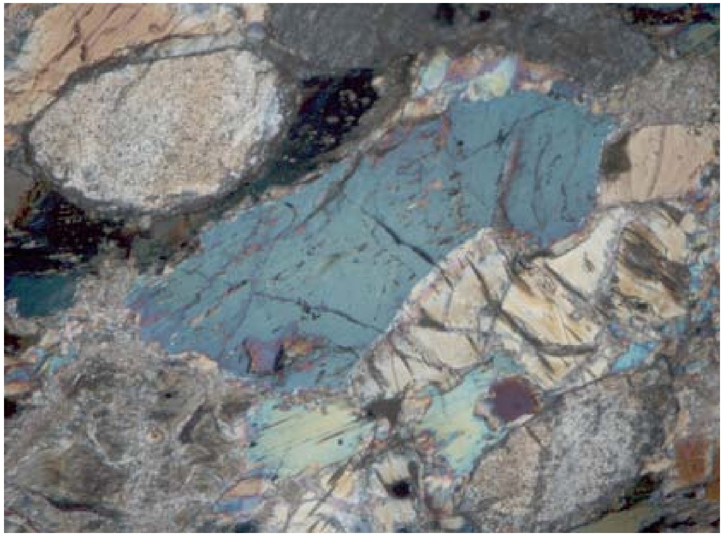
Retardation

If we look down a microscope with no thin section present, what is the colour of the light?

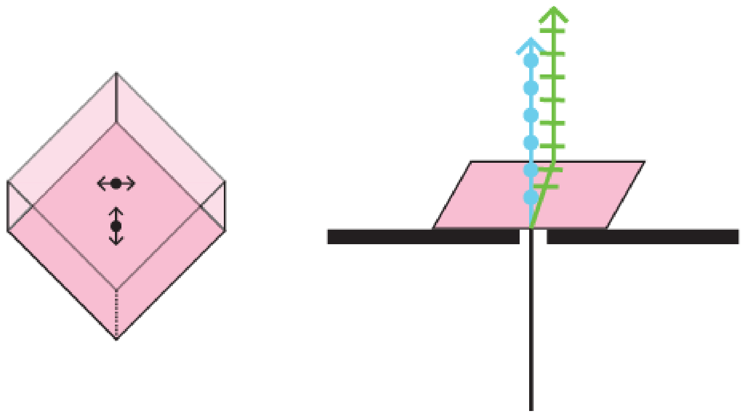
What happens when the polarisers are crossed?

What happens if we place a thin section of anisotropic minerals in the light's path?



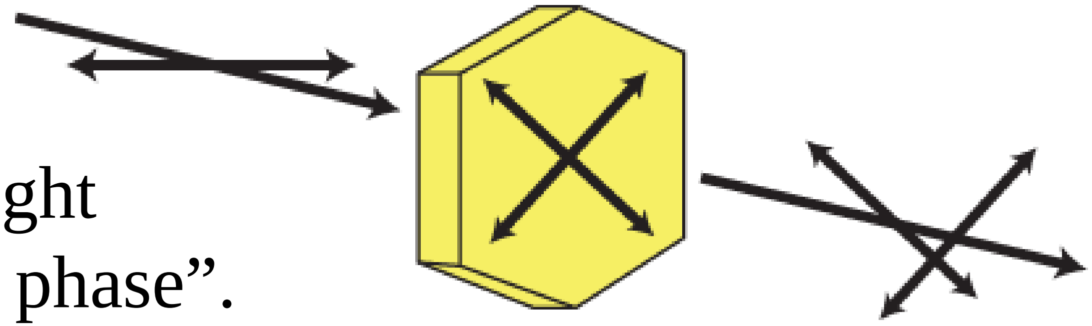


When **monochromatic** polarised light enters an anisotropic mineral it splits into perpendicular components (excluding the special case): the two light beams are independent.

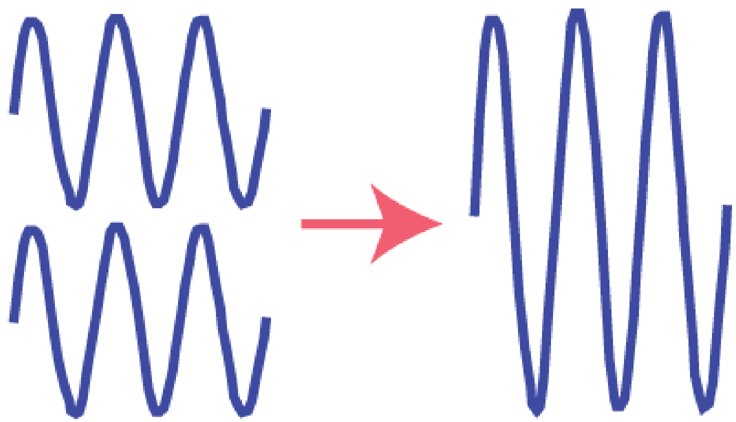


The RI of a mineral varies as a function of the crystallographic axis. Therefore, the two beams are created simultaneously but exit at different times.

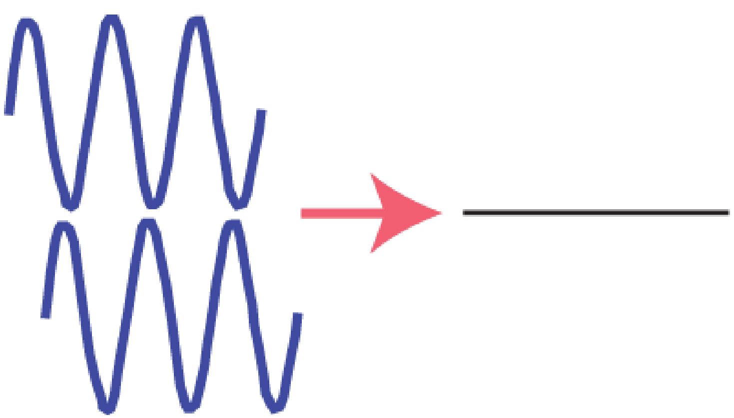
Therefore, the exiting light consists of two light beams that are "out of phase".



Constructive vs Destructive Interference



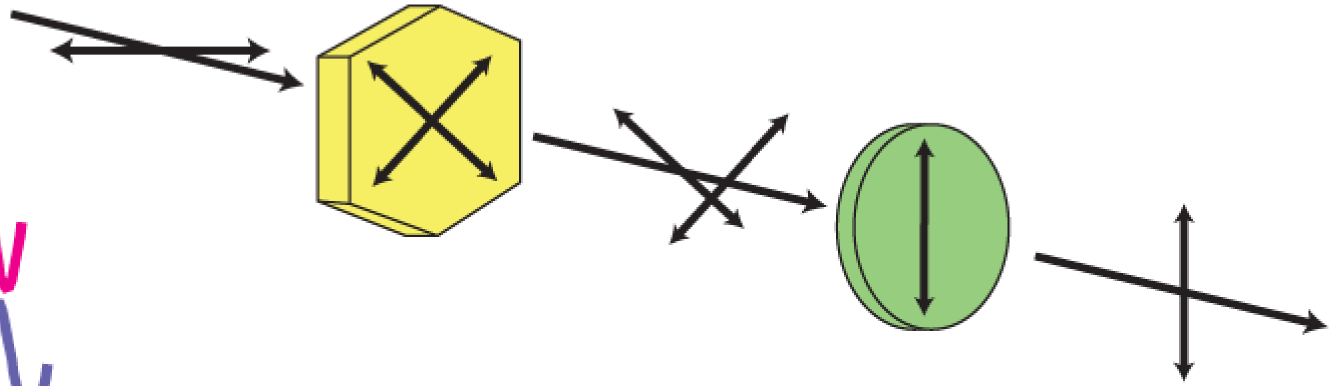
Constructive waves – same l
Double the amplitude.
Brighter light!

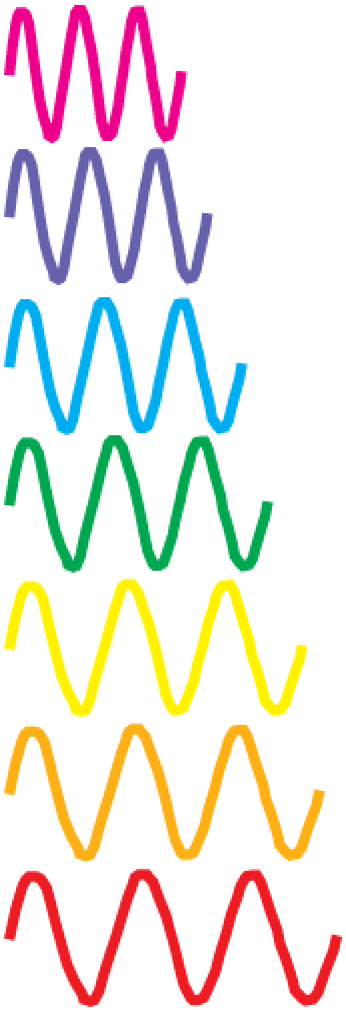


Destructive waves.
No light.
Darkness!

The intermediate situation results in light, but of intermediate intensity (brightness).

What happens when the incident light is white?

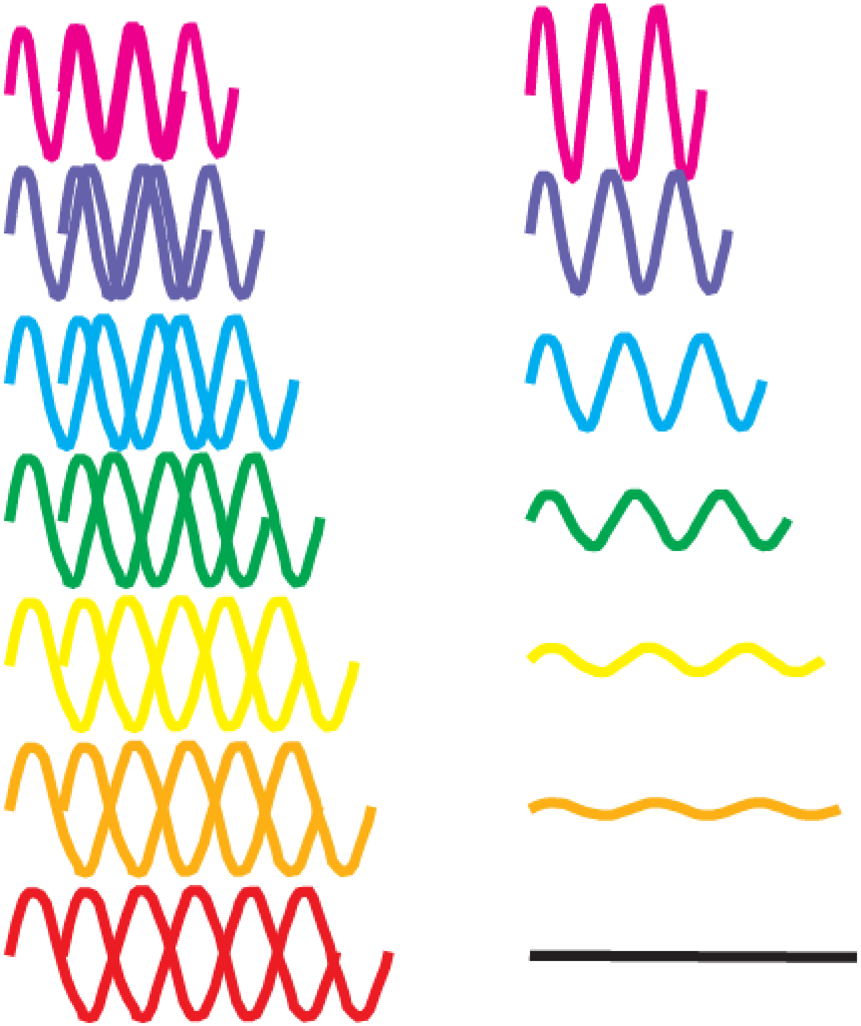




Depending on the RI and thickness of the crystal the some light waves exiting the crystal will interfere destructively, while others interfere constructively.

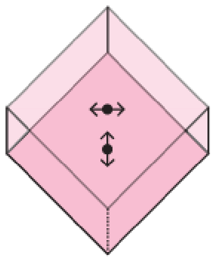
When a colour wavelength is removed from white light, we get coloured light.

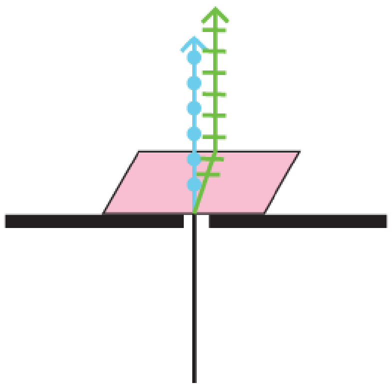
In a case where the longer l are retarded ~½ l, the resultant colour is dominated by blue/violet.



The meaning of retard, is to hold back. So, in this case, the red light has been held back ~½ l.

The difference in the number of l is the ***path difference*** or ***retardation***.





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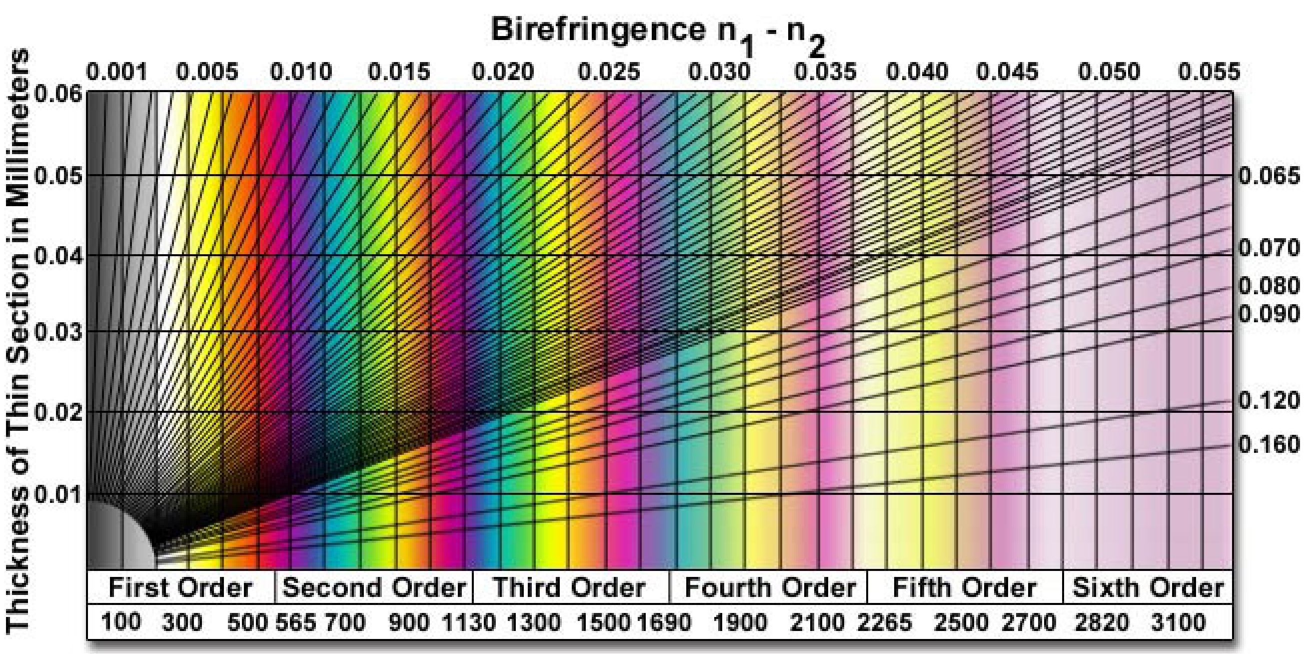


The interference order is a measure of retardation (path difference).

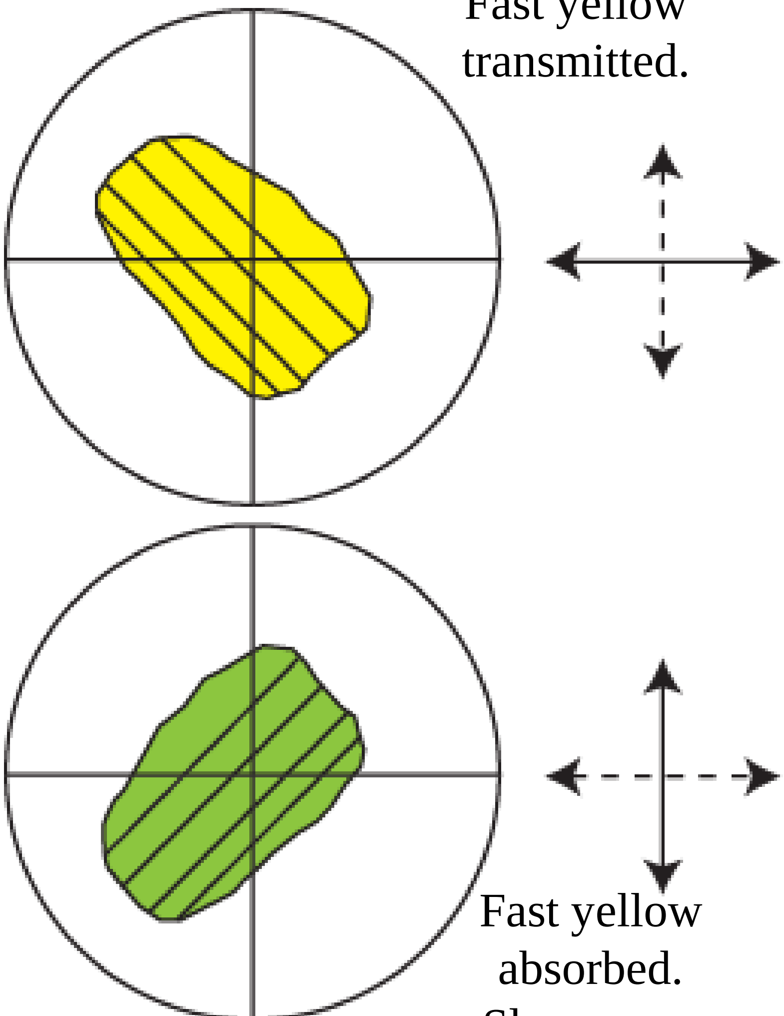
Other Consequences of Double Refraction

Colour and Pleochroism

In plane polarised light, the effects of double refraction is that some minerals are coloured – the reason is similar, but slightly different from general mineral colour (discussed previously).

Tourmaline Acorn. Crystal thickens from top-to-bottom. Therefore, the retardation of doubly refracted light increases.

Pleochroism



Plane polarised light is vibrating in one plane (E-W).

When a mineral double diffracts the light into a fast and a slow travelling wave (perpendicular to one another) the orientation of the mineral controls the absorption of the light.

One vibration direction is completely absorbed in one orientation, and the other when the mineral is rotated 90°.

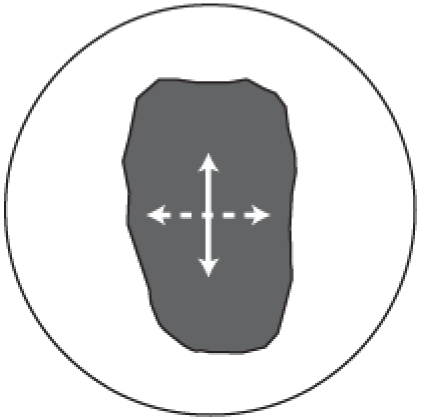
Length Fast and Length Slow

Sign of elongation

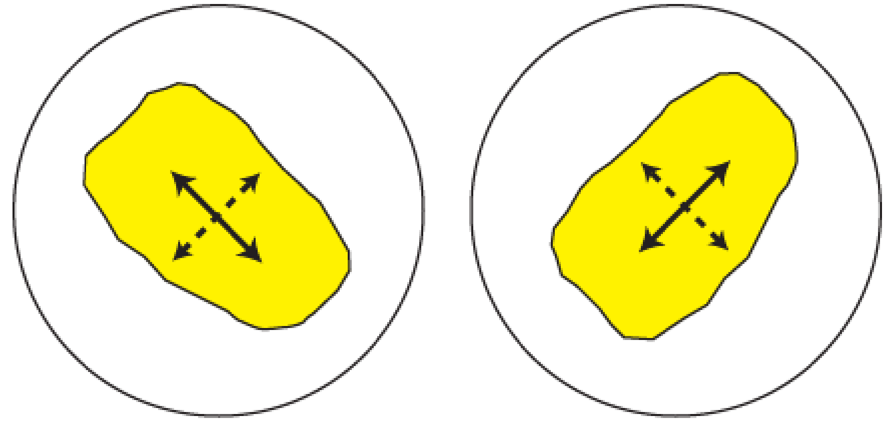
As seen previously, the two light waves generated by anisotropic minerals have different velocities, controlled by the refractive index.

These two vibration vectors may be referred to as the fast and the slow – naturally!

How does one determine which vibration direction is fast and which one is slow?



A Mineral with straight extinction in XPlrs has maximum birefringence at 45°

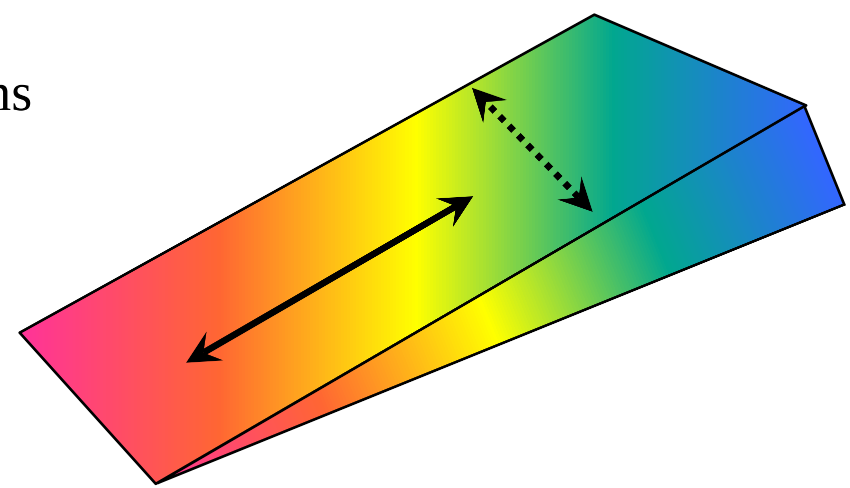


The birefringence is caused by retardation.
Note – there is not always pleochroism.

By using an accessory plate the petrologist can artificially augment or hinder the retardation.

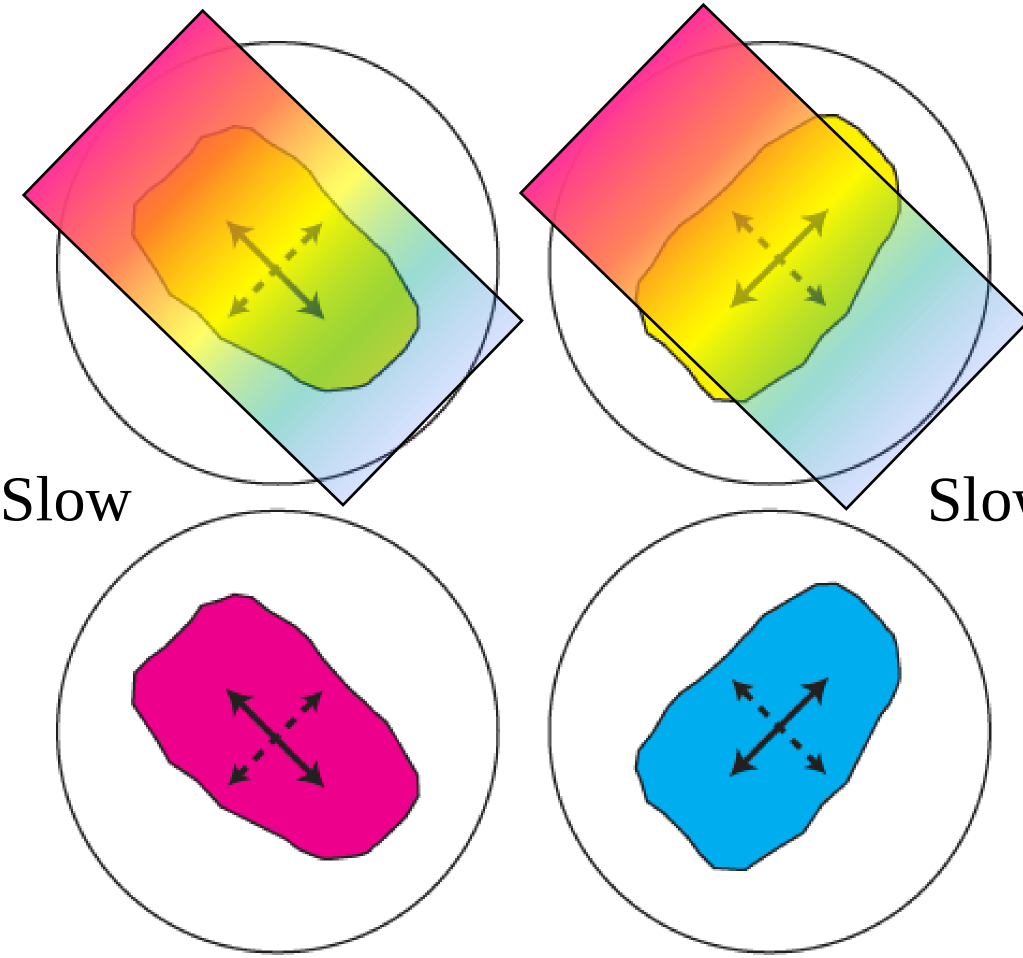
The accessory plate is a wedge of mineral specially cut such that its vibration directions are known.

Typically, they are length fast.



When the accessory plate augments the retardation (i.e. increases the path difference) the order of birefringence colour increases.

Slow on Slow



Slow on Fast

When it reduces the path difference, the birefringence colour decreases.