Advanced optics: retardation and interference figures

Retardation (path difference) depends on the degree of double refraction in a mineral section.

Double refraction depends on:

1. The orientation of the mineral section with respect to its lattice.
2. The minerals birefringence.

Birefringence in anisotropic minerals is maximised when the difference between the refractive indices is maximised.

To view this maximum we must examine a crystal section in a specific orientation.

Uniaxial Minerals

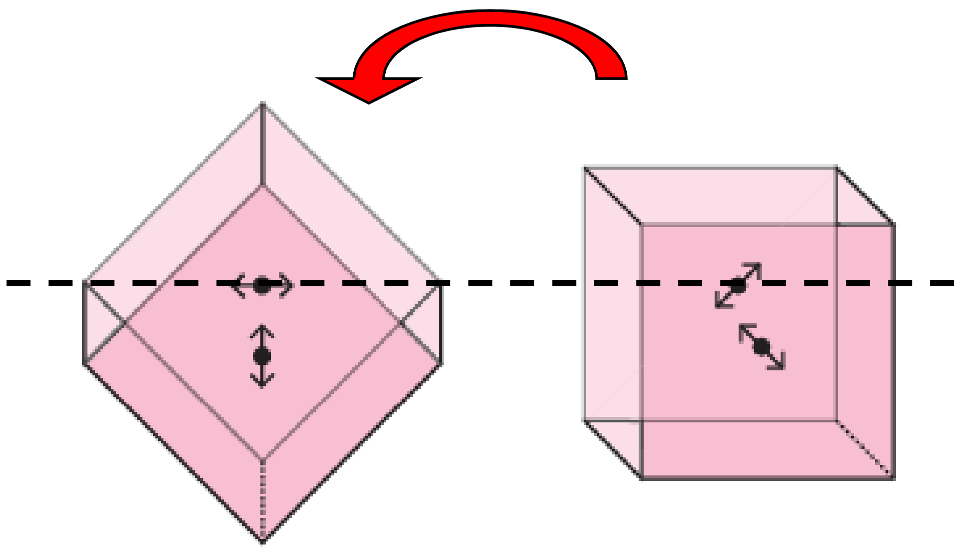
Minerals with two or three equal crystal axes that lie in a plane perpendicular to an axis of a different length are all **UNIAXIAL**.

This, single axis, parallel to the crystallographic *c* axis is also called the minerals **OPTIC AXIS**.

Which crystallographic systems are we talking about?

When light is shone down the optic axis it behaves in the same manner as expected when interacting with an isotropic mineral.

When light is shone in any other direction, what happens?



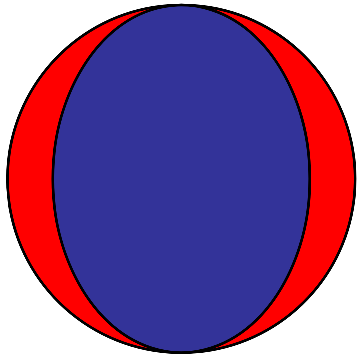
Something else happens too when the calcite rhomb is rotated.

On rotation, one dot remains stationary, while the other rotates with the calcite.

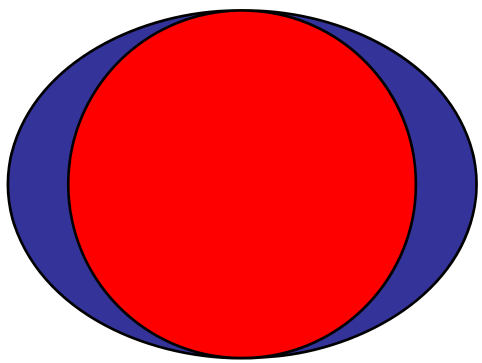
The stationary light vibrates in the basal plane and no matter the degree of rotation always travels the same distance in the same time – this is the ***Ordinary (O) wave***.

The second beam, vibrating in the plane of the optic axis travels different distances depending on orientation. This is (the) ***Extraordinary (E)*** (behaviour) ***wave***.

Uniaxial minerals are divided into those that are positive and negative.



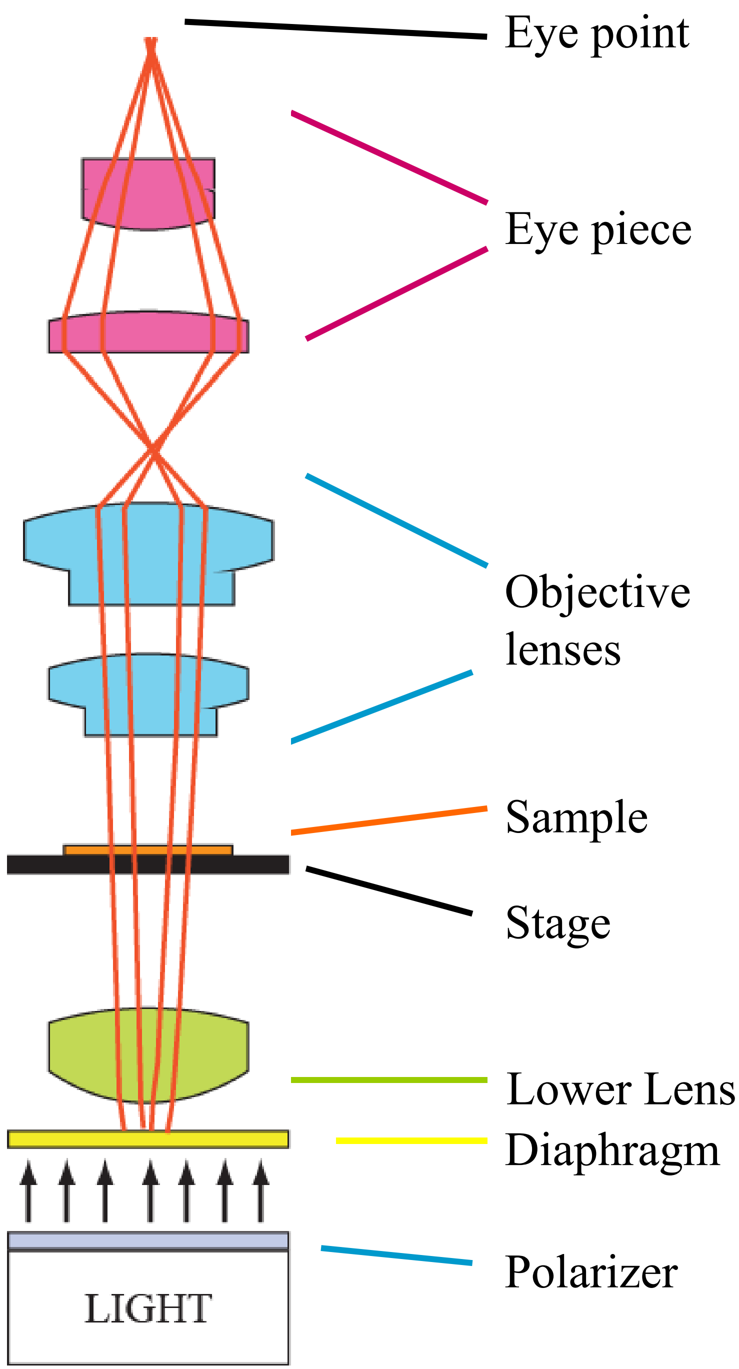
When ordinary wave, which travels an equal distance in all directions, has a greater velocity, the mineral is positive.



When ordinary wave, which travels an equal distance in all directions, has a lower velocity, the mineral is negative.

The two light rays are indicative of two refractive indices in uniaxial crysals.

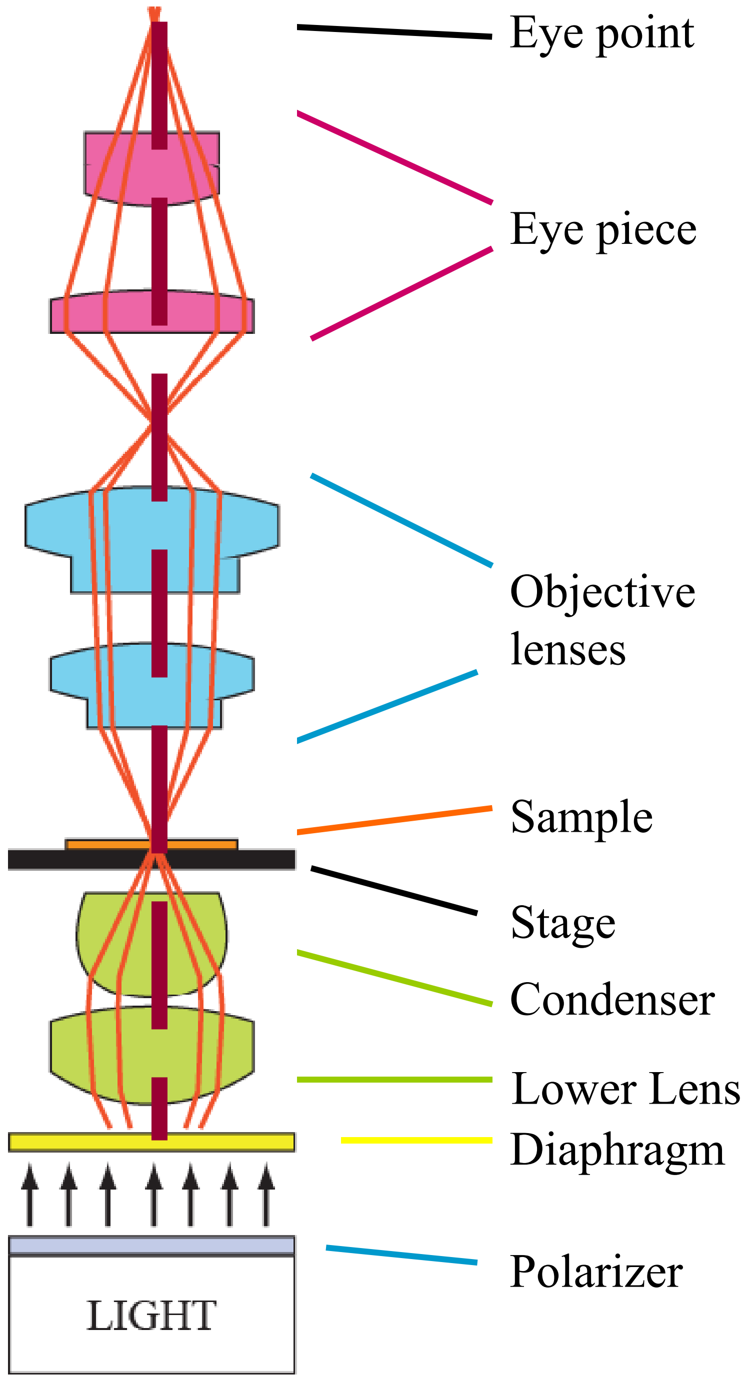
Vibration along the O wave is designated ω (Omega).
Vibration along the E wave is designated ε (Epsilon)



All light passing from the source, through the polariser, to the sample travels parallel to the vertical.

This light, when entering an anisotropic crystal with the special orientation – optic axis parallel to direction of light propagation – passes straight through and is not split in two. This mineral is extinct when viewed down the microscope with the polarisers crossed.

See earlier lecture.



When the condenser is inserted all the light is strongly converged and only some of the light enters parallel to the optic axis.

Therefore, only some of the light enters the crystal and passes straight through.

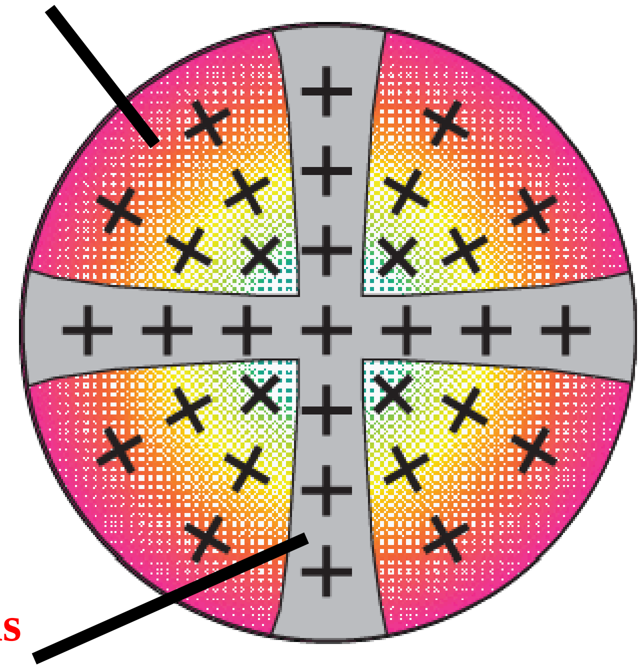
All light that enters the crystal oblique to the optic axis is split into its mutually perpendicular vibration directions, and therefore is susceptible to the normal processes of retardation and birefringence.

Identifying Uniaxial Crystals in Convergent Polarized Light.

This is done by constructing an *interference figure* (also known as the *optical indicatrix*).

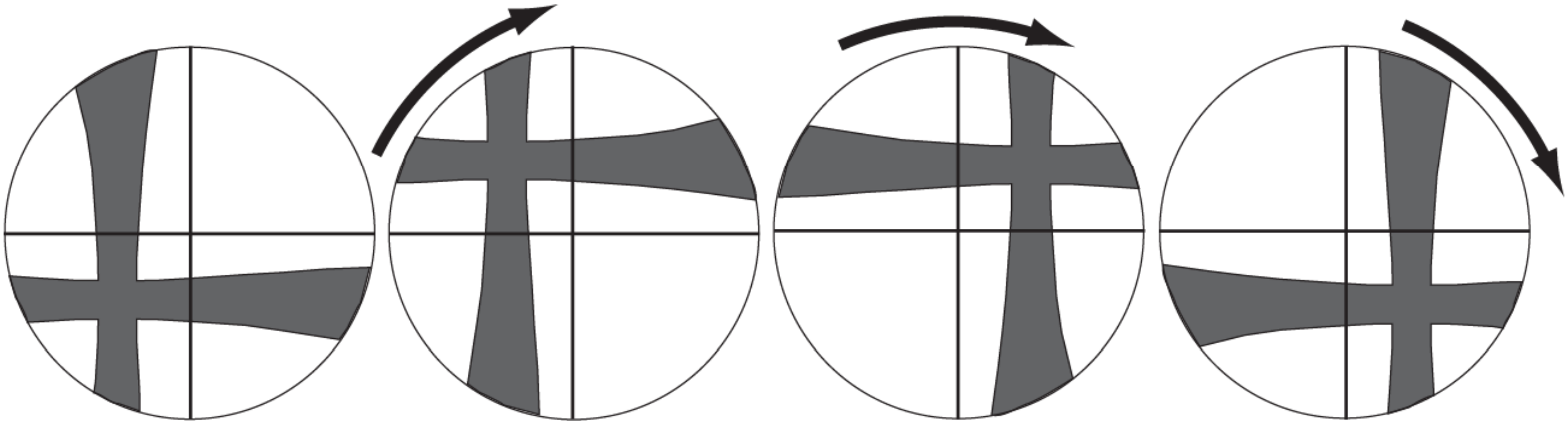
"The indicatrix is constructed so that the indices of refraction are plotted as radii that are parallel to the vibration direction of the light".

Light is oblique to optic axis, therefore is doubly refracted.



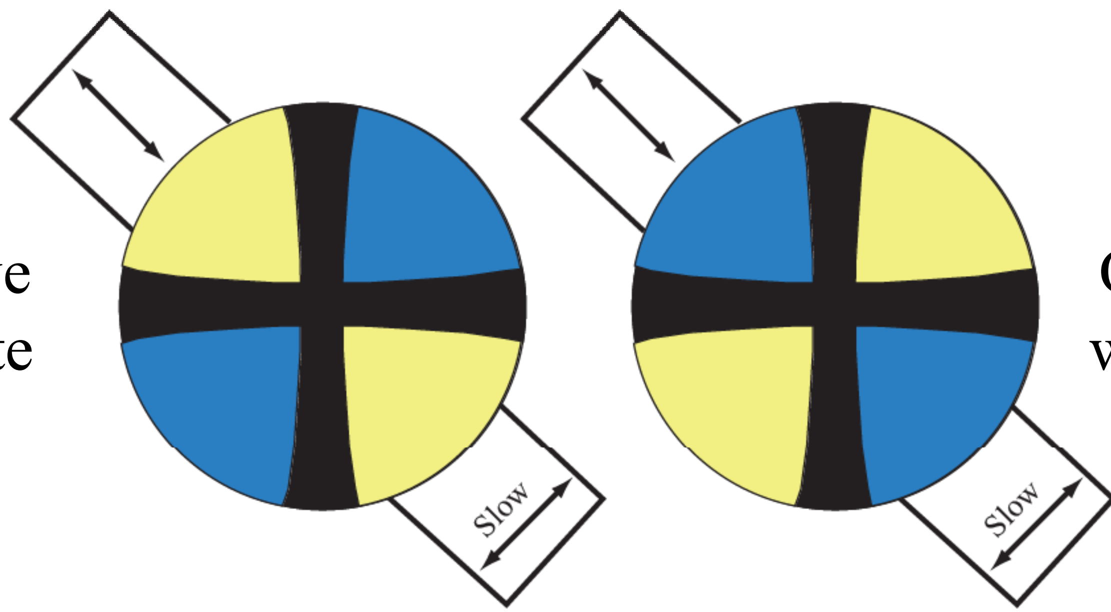
Light parallel to optic axis enters mineral and is not split in two, so passes straight through.

More realistically, you identify a mineral grain with no, to minimal variation in birefringence (i.e. black in XPlrs), insert the sub-stage condenser, insert the Bertrand lens, use highest magnification, and open the diaphragm.



Off-centred uniaxial figures can also be used for identification purposes. The limbs should always be horizontal and vertical, even if the centre moves to edge of the field of view.

Optically +ve with tint plate



Optically -ve with tint plate

Biaxial Minerals

Minerals with the lowest symmetry and three crystal axes of unequal length, and in <u>most</u> cases one inter-axis angle $\neq 90°$.

So called because they have two directions in which light travels with zero birefringence (i.e. two **OPTIC AXES**).

Which crystallographic systems are we talking about?

Light entering biaxial minerals is broken into two rays – a fast one and a slow one.

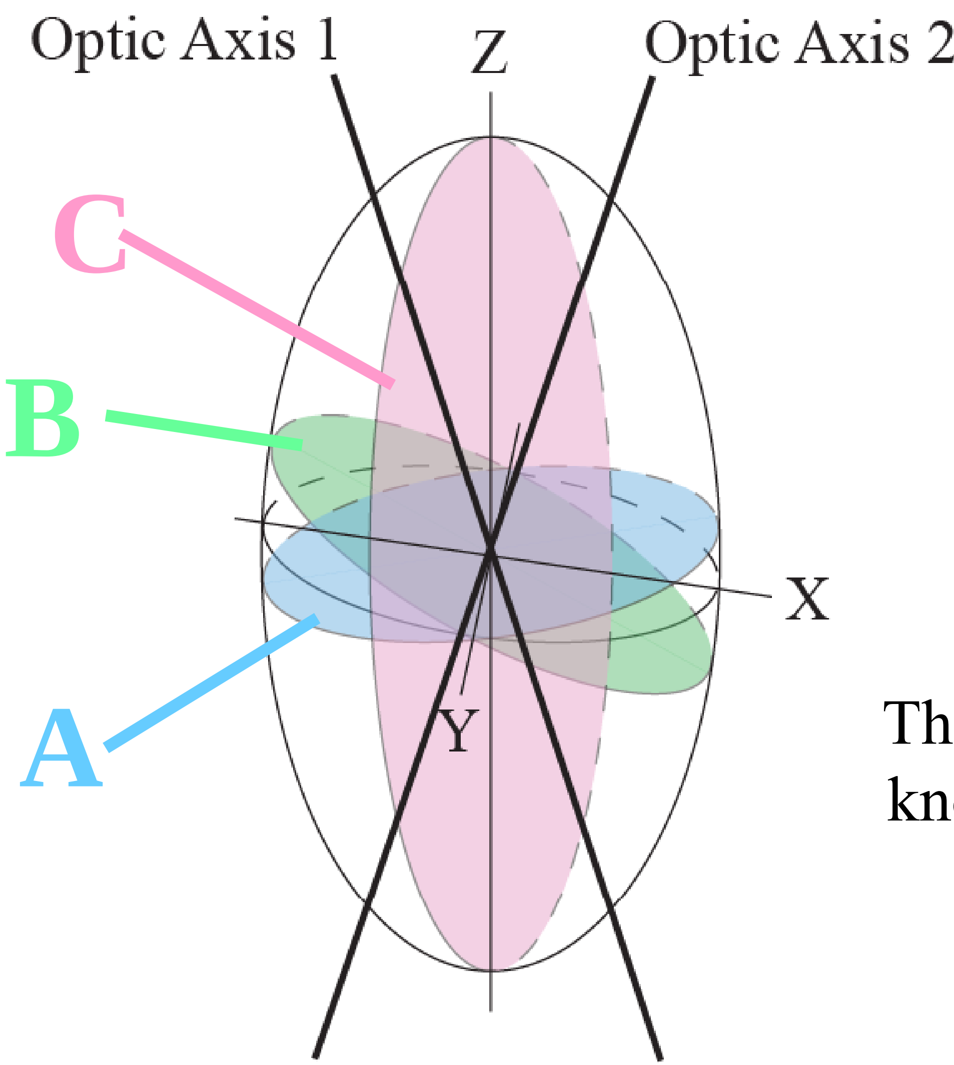
However, both waves are “extraordinary”.

Biaxial minerals have three unequal crystal axes.

Subsequently, these minerals have **three** refractive indice values i.e. each value of n is **different**.

Important: Unlike the crystallographic axes the three optical directions are always at right angles to each other.

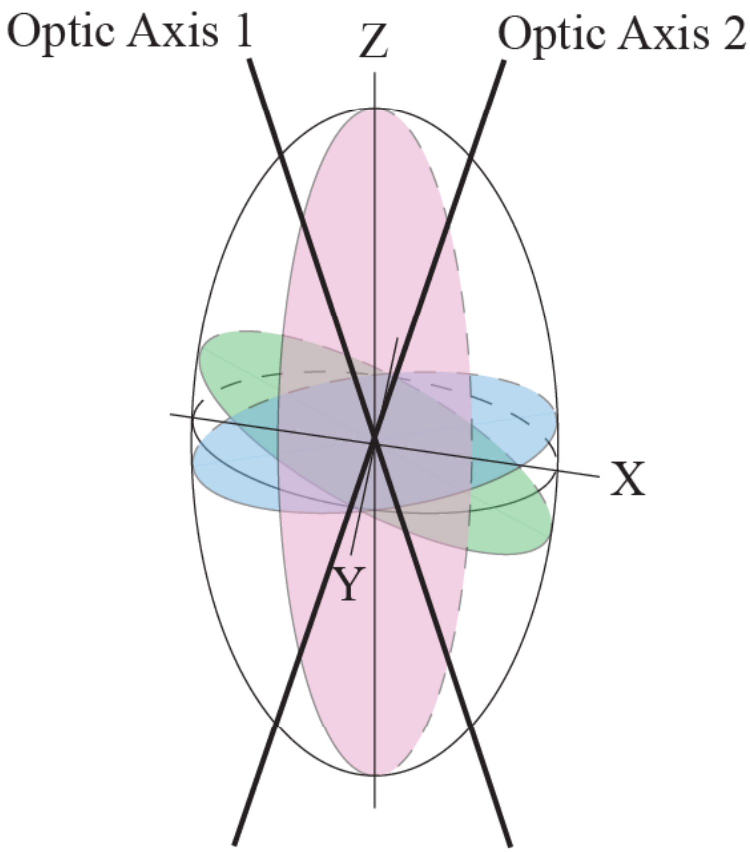
We represent the three optical directions by means of the biaxial indicatrix.



The birefringence is maximum when a section is cut parallel to X and Z.

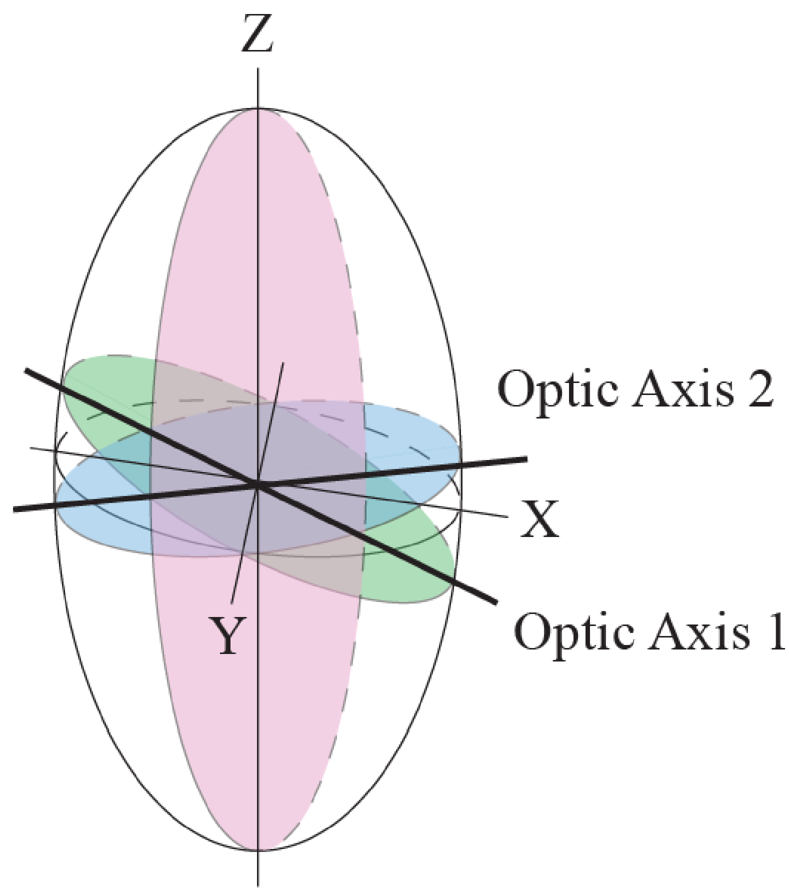
Light travels parallel to Y.

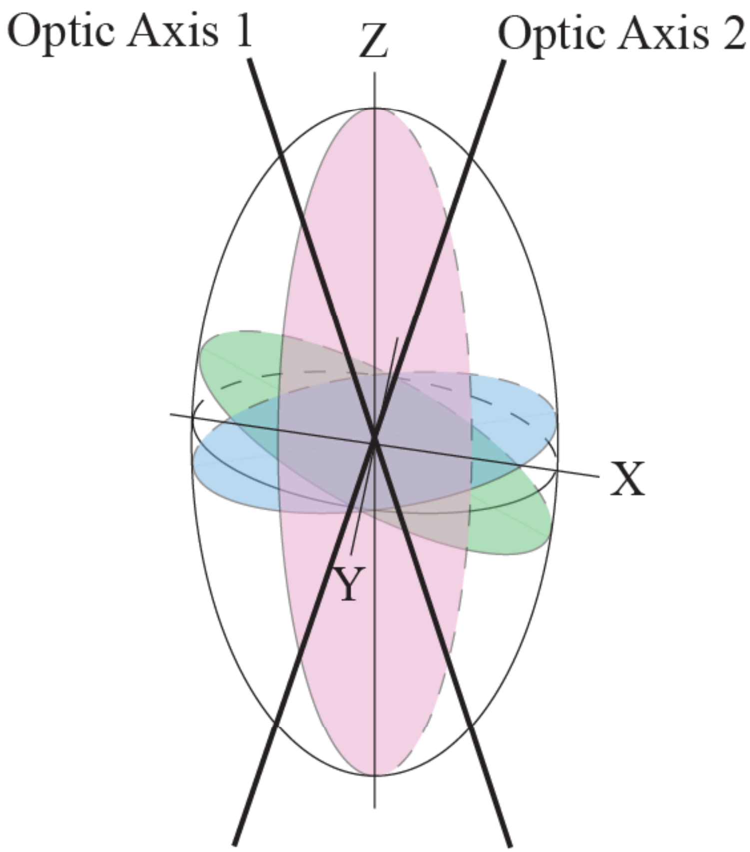
The angle between the two OA is known as *optic axial angle* (2V).



When 2V is acute around Z
the mineral is positive.

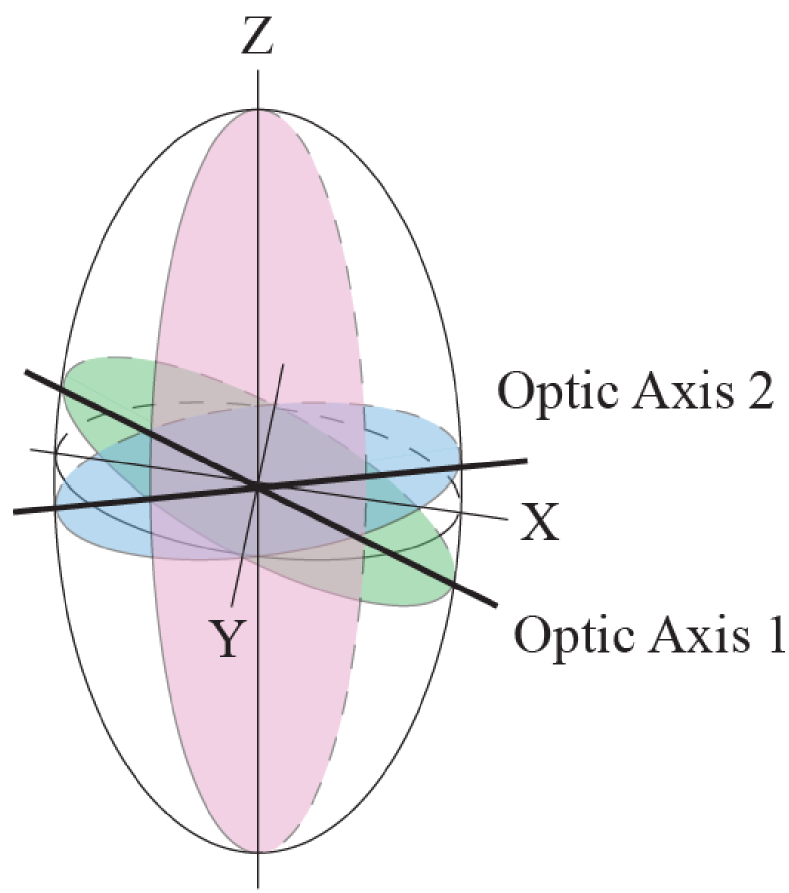
When 2V is acute around X
the mineral is negative.





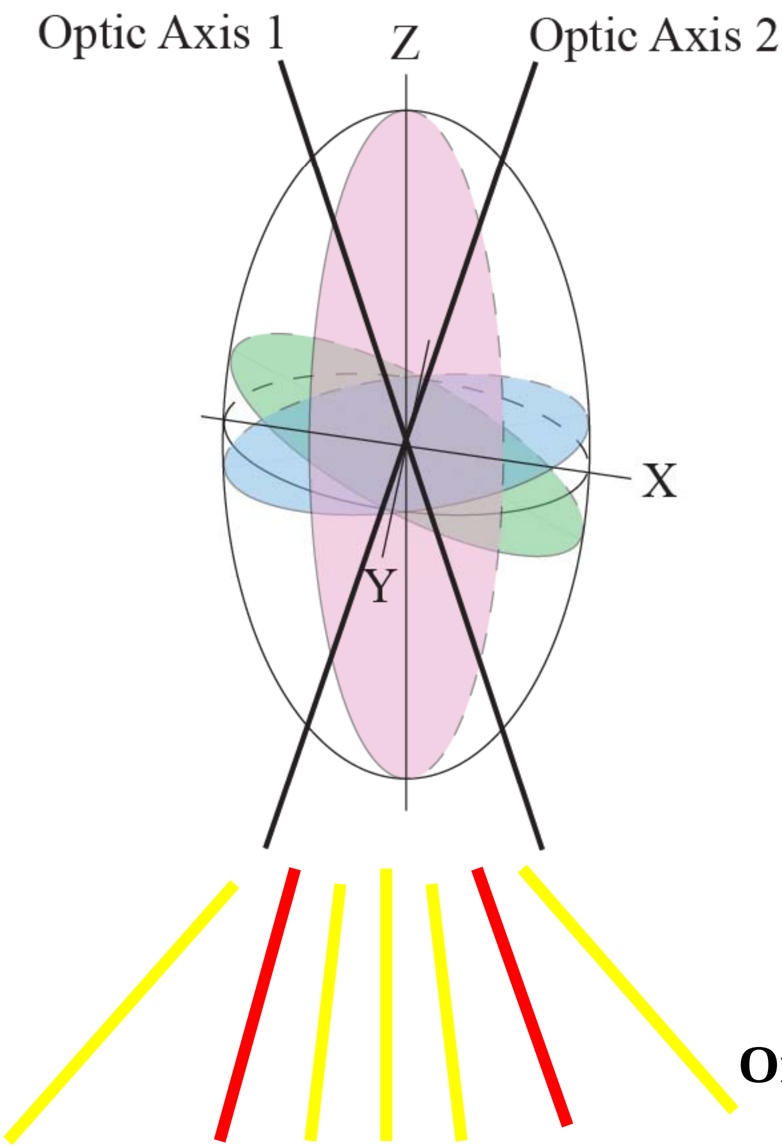
If the mineral is positive, Z is the acute bisectrix, and X the obtuse bisectrix.

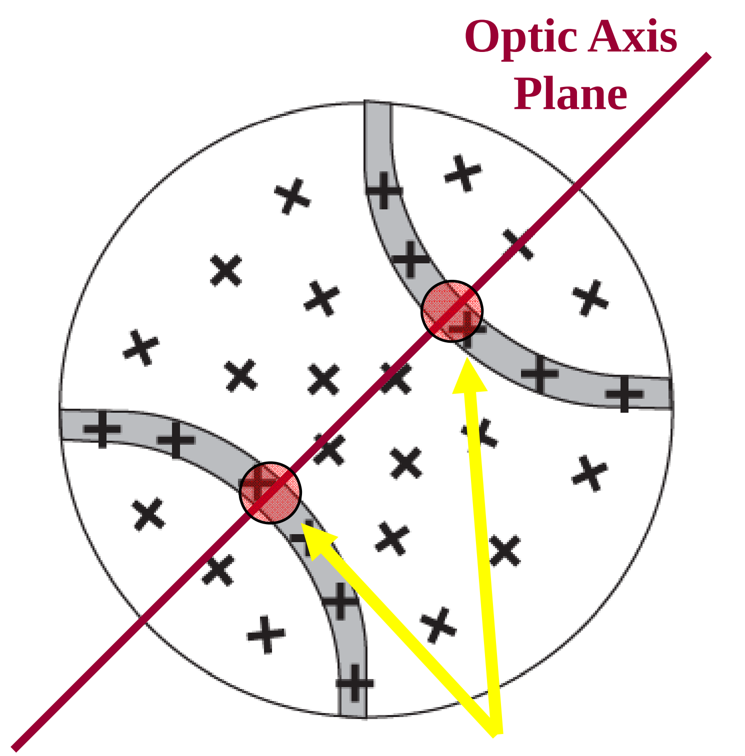
This is reversed for negative minerals.



The optic axes always lie in the XZ plane, which is called the *optic axial plane* (OAP)

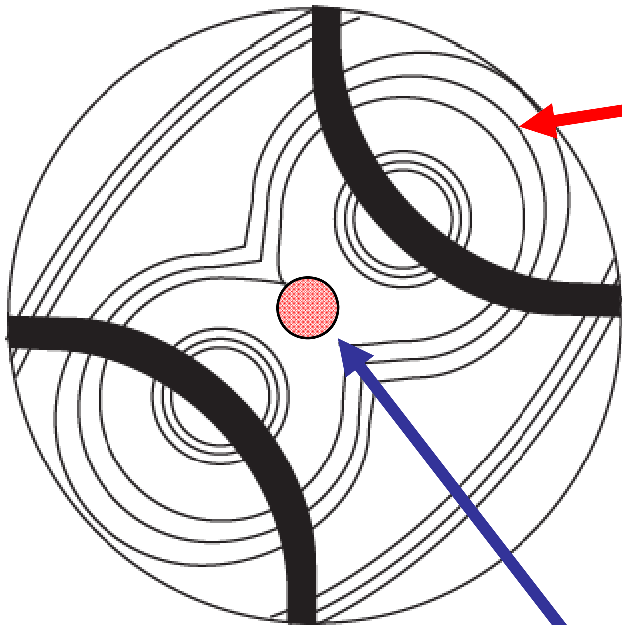
What does the biaxial indicatrix look like?





Melatopes – (M) mark the points of emergence of the optic axis.

Only light entering parallel to an optic axis passes without being split.



Each line represents an "isochrome" of birefrengence

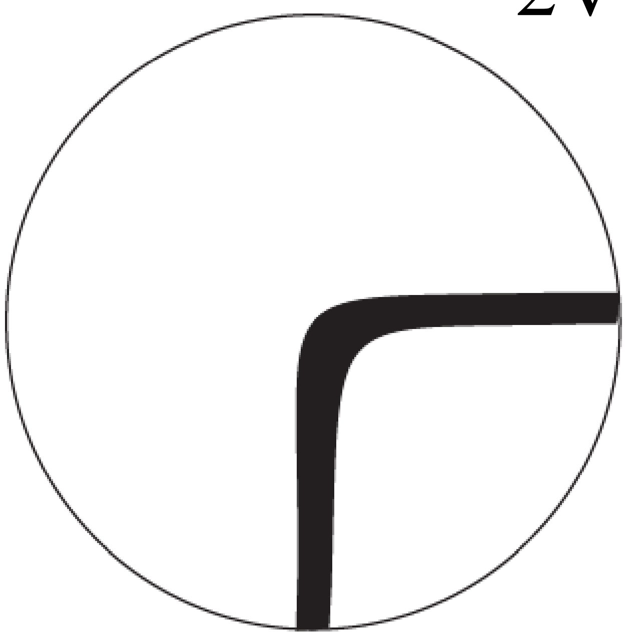
Each extinguished line in the optical image is called an isogyre.

Looking down the c axis.

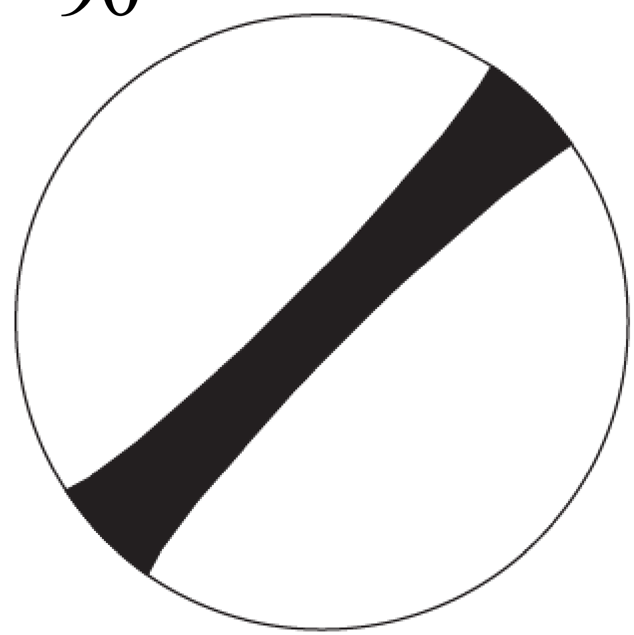
If you have a crystal oriented so that you are looking straight down the c axis you can measure 2V using simple geometry.

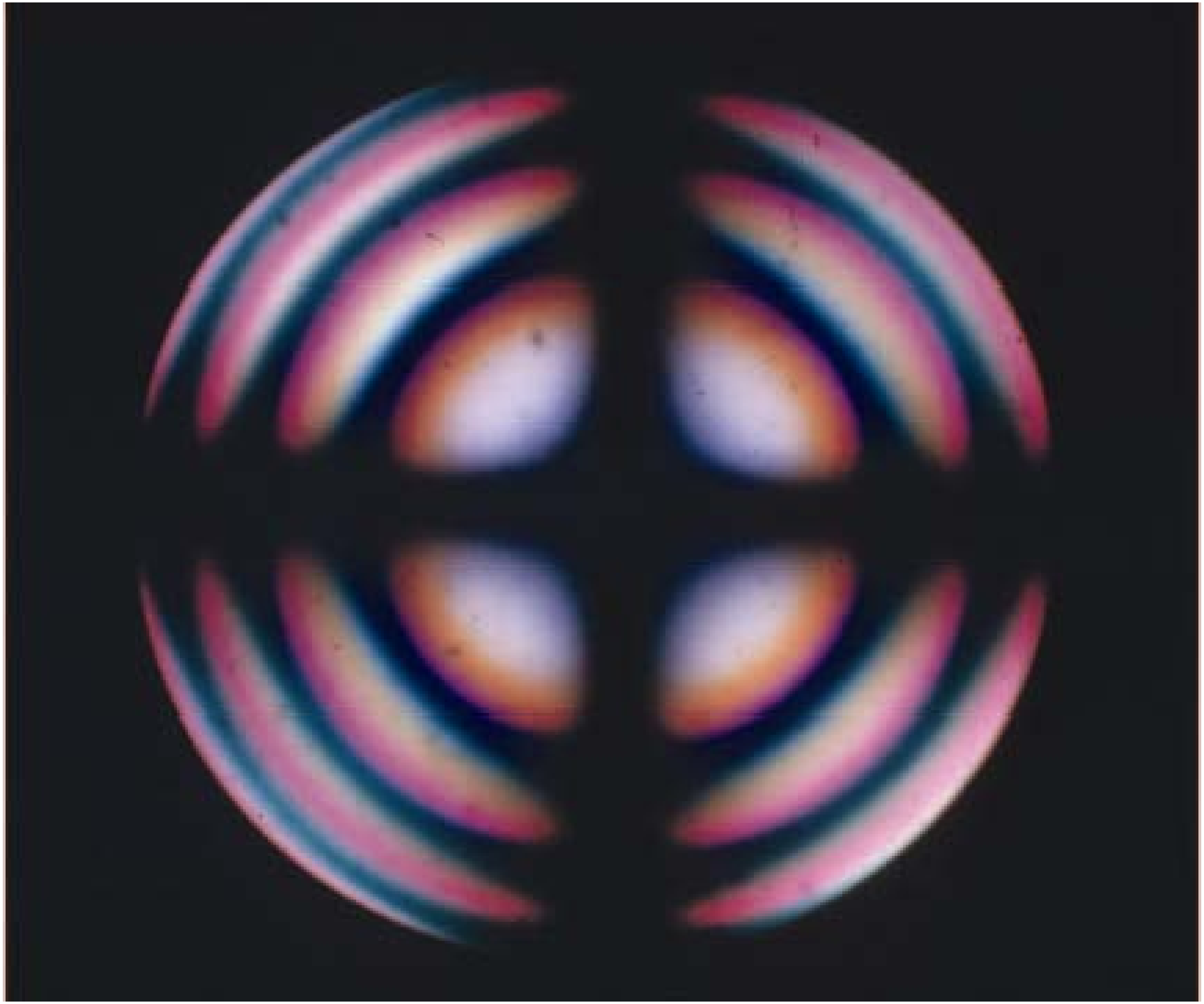
If you have a crystal oriented so that you are looking straight down one of the optic axis i.e. you only have one isogyre in the field of view, it is still possible to estimate 2V.

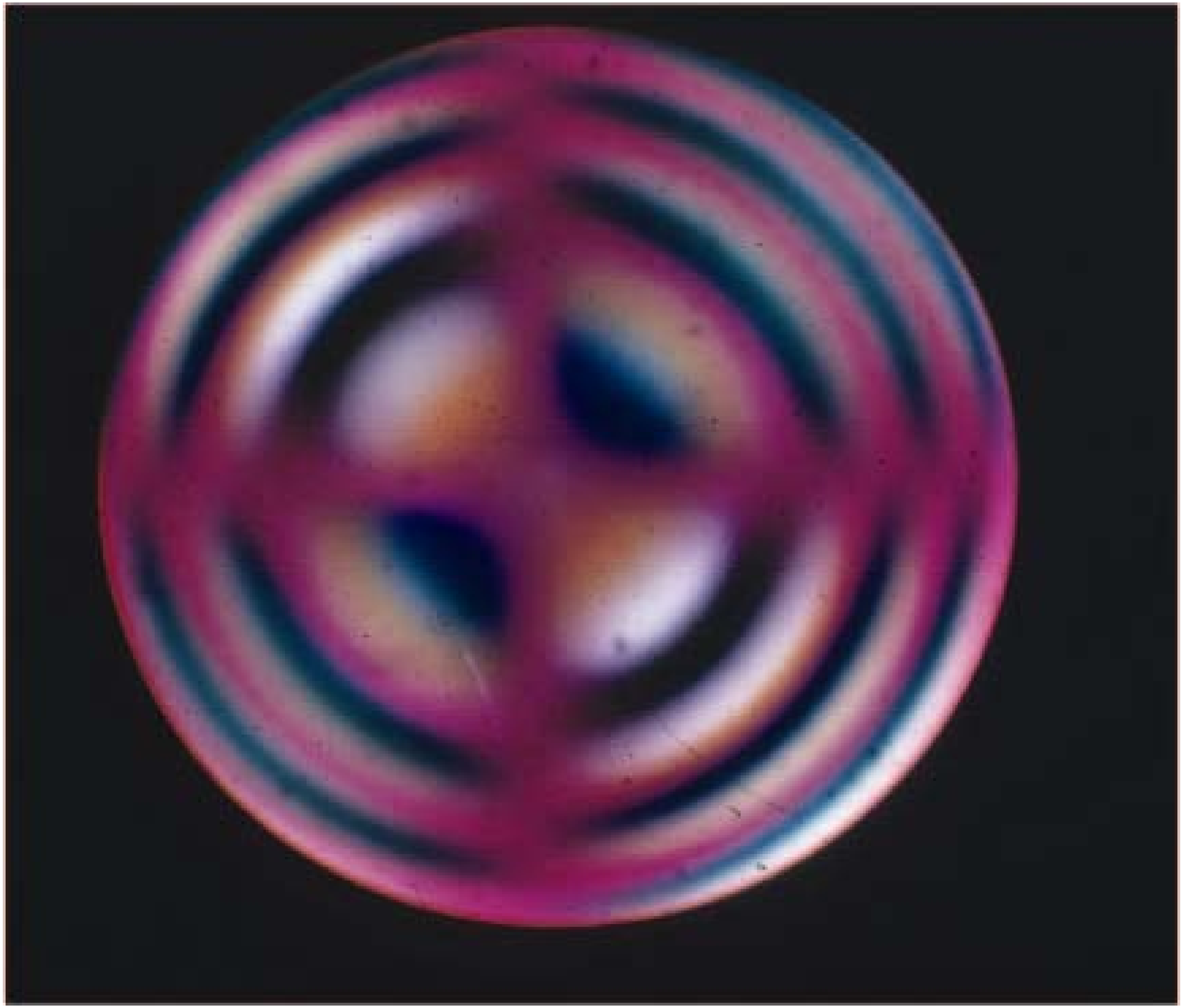
$2V = 0°$

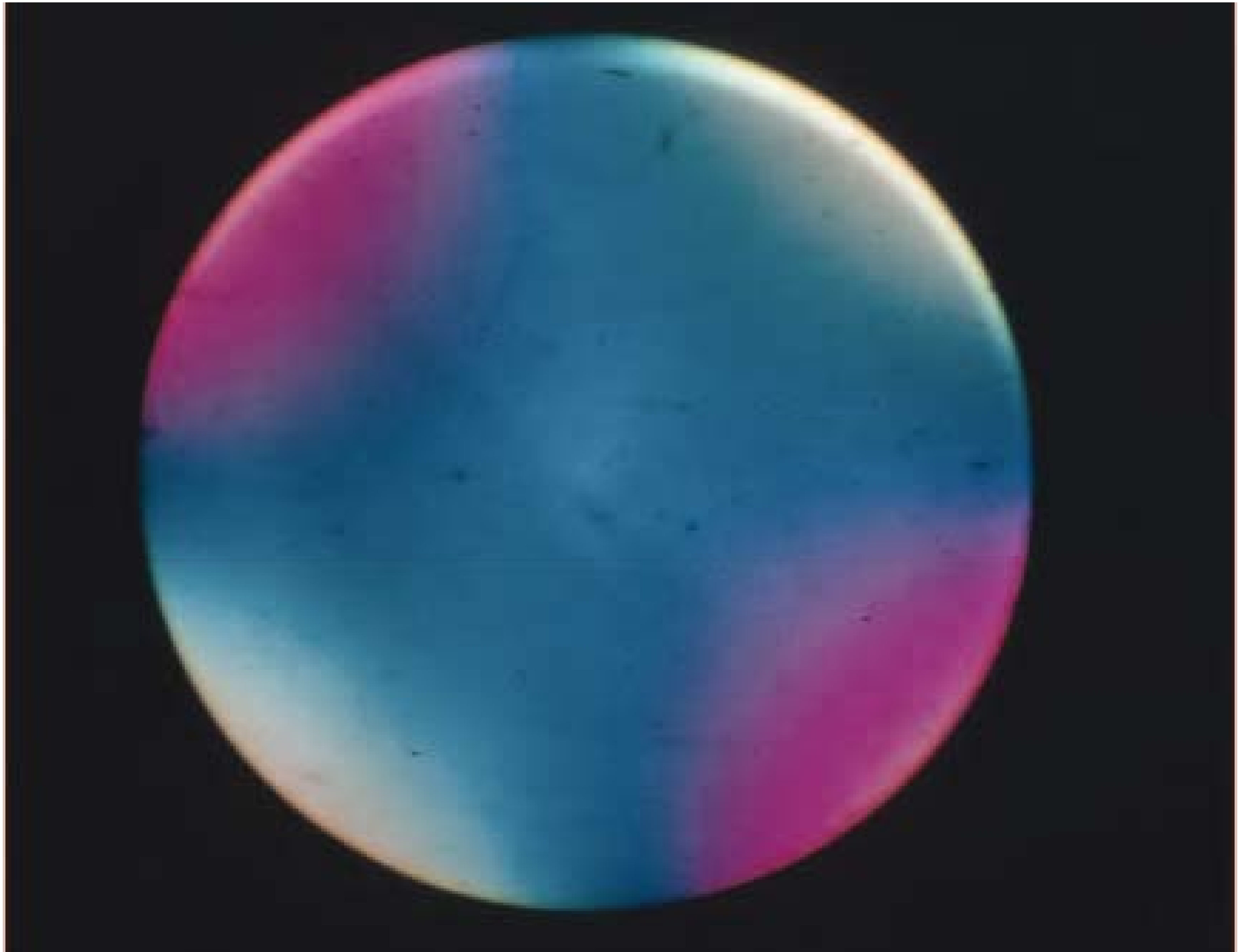


$2V = 90°$









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