Optical Mineralogy

To study rocks & mineral in thin section, we make use of the physics of light as it travels through a medium (the minerals being studied). Though light has both a wave and a particle nature, in optical mineralogy we use the wave nature of light to describe the behavior of light through minerals.

This study is very detailed, and to follow through it thoroughly we'd have to spend at least a whole semester on the topic. The purpose of this course, however, is not to totally understand the physics of the optics we are using, but to use optical methods in the identification and understanding of igneous and metamorphic rocks. I would like to show, not the details of the optics, but just enough of the information for you to see why we can use the petrographic microscope and why you see what you see through it. Therefore, these notes are meant as a background, and not to be a complete study on their own. This material consequently is incomplete and may not follow as logically and easily as if we included all the necessary details here. Many of these notes are from my own class notes, and some may be more useful or understandable than others.

For a better treatment of the subject, or more detail, I recommend a text on optical mineralogy. I have always thought highly of Wahlstrom’s text, but shorter treatments are given by Klein & Hurlbut, Nesse, and many others.

Light waves are a form of electromagnetic energy. They are subject to reflection, refraction, diffraction, dispersion, interference, polarization, and other such processes.

![EM waves have wavelength, amplitude as shown above.](image-url)
Index of Refraction

\[ n_{\text{substance}} = \frac{c}{v} \]

\( n \) = index of a substance or xlline medium
\( c \) = veloc of light waves in a vacuum and is abritrarily assigned a value of 1
\( v \) = veloc of light waves for a particular \( \lambda \) in a specified medium

Examples of \( n \)

- \( n \) air at sea level = 1.00029
- \( n \) air dry at 15C = 1.000274
- \( n \) water at STP = 1.330
- \( n \) fluorite = 1.434
- \( n \) Si\( \text{O}_2 \) = \( n_e \) = 1.553
  \( n \) \( w \) = 1.544

**Snell’s Law:** \( \frac{n}{\sin i} = \frac{\sin r}{\sin r} \) amount of bending or refraction of the light as goes from one medium to another

\( i \) = angle of incidence
\( r \) = angle of refraction

\[ n = \frac{\text{distance light travels in a vacuum}}{\text{distance light travels in a xlline medium}} \] at the same time interval

Snell’s Law does not apply to anisotropic media

It does apply to the O-ray, but not to the E-ray
Constructive and Destructive Interference
result from superimposing 2 (or more) waves upon each other
Wave Fronts

Travel of light through a medium in wave fronts
from Wahlstrom, 1979

When we look at light through minerals, we are looking at more than just one ray. Multiple rays of light travel in wave fronts. The Huygenian constructions below illustrate that light from a single source travels in phase, whether in plane or from a point source.

These wave fronts are affected by the medium they travel through. Compare the diagrams for isotropic and anisotropic media below.

Relief

Relief in minerals is a consequence of differing $n$ of neighboring mineral grains. Light is refracted at an interface more strongly by a larger difference of $n$ at the interface.
The Nichol Prism
How light travels through the polarizers and mineral.

The Nichol Prism (which now can be constructed from modern materials) polarizes light by splitting into a slow and a fast ray, which are mutually perpendicular.

The result when viewing a mineral between crossed nichols is that the light has been split into a slow and a fast ray, mutually perpendicular, which are resolved by the upper nichol into interfering rays. This interference is the basis for mineral identification under the microscope.

**Extinction**

Extinction occurs when all light is blocked by the opposing polarizers. In minerals, this occurs when the vibrations directions of the light passing through the minerals are aligned with the upper and lower polarizer directions.
Examples of different ways polarized light passes through the polarizers and x1.
Crystallographic/Optical Directions in Quartz

Fast and slow rays are resolved into same directional components, where they interfere with each other causing interference colors.

Interference colors depend on the velocity of the slow and fast rays, path difference (phase difference) of rays, and thickness of mineral grain or thin section.

Constructive interference: Rays are in same phase and additive.
Destructive interference: Rays are in opposite phase and subtractive.

**Crystallographic/Optical directions in Calcite (indicatrix)**
Uniaxial Indicatrix and Ray Surface Velocities
A way to visualize how light rays and vibration directions occur in crystals.

The Indicatrix is a visualization of vibration directions in crystals. \( n \) is shown proportionally with longer lines for the larger \( n \). Since velocity is inversely proportional to index of refraction, the slower ray has the higher \( n \) and is shown to be larger.

Ray velocity surfaces are a continuation of the indicatrix idea, and the vibration directions of the rays are shown as they intersect the contracted surfaces from the indicatrix. When we can visualize the vibration directions of light in a crystal, we can advance to looking at the skiodrome.
Skiodromes

Skiodromes are a way to visualize how light is vibrating in a crystal. This uses a converger to create a point source of light below the crystal, and projects it above the crystal onto an imagined hemispherical surface. Vibration directions show as radial lines and perpendiculrars to those lines. Where these lines are parallel and perpendicular to the polarizers, they will be blocked by extinction forming an isogyre. The directions that are not perpendicular or parallel to the polarizers will not be blocked by extinction, and will not be part of the isogyre.

Isotachs are the lines (blue) that show the vibration direction of emerging rays.

The N-S vibration directions coming out of the skiodrome will be cut out by the analyser and will form isogyre.

Original E-W light was cut out by polarizer, but some light was bent through the mineral into E-W components. These are resolved to E-W by analyzer.
Uniaxial Interference Figures

Isogyres represent extinction of N-S and E-W light vibration directions in the skiodrome.

These are the uniaxial interference figures.

1. Maltese Cross = optic axis figure
2. off-center optic axis figure
3. flash figure

Note how insertion of test plate compares fast and slow rays with the slow ray of the test plate, and shows how constructive or destructive interference will cause a certain color pattern with insertion of test plate. (Also see next page.)
Test Plates – Uniaxial Figures

Quartz Wedge (1 to 3 \( \lambda \))

Gypsum Plate (1\( \lambda \))

Mica Plate (1/4 \( \lambda \))
Biaxial Indicatrix

A biaxial indicatrix is a way of seeing what kind of optical figures you will see when looking at a particular crystallographic direction. While each kind of figure has its use, in this class we will try to focus on the “simple” figures – the BxA, OA, and ON.
Biaxial Index Indicatrix
Showing the 3 planes separately

\( B \times A = Z \)  
\( B \times O = X \)  
\( n_a = \frac{1}{2}, \; n_b = \frac{1}{2}, \; n_c = 2 \)

\( B \times A = X \)  
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(+) Positive Minerals

(-) Negative Minerals

\( xz \) Plane = Optic Plane

\( yz \) Plane

\( xy \) Plane
Biaxial Ray Surface Velocity Constructions
This shows how light vibrates in a biaxial crystal

Unlike the diagrams for uniaxial crystals, these are not shown in 3D, but each of the 3 planes is shown separately.
Biaxial Skiodrome

Top Line: BxA Figure, BxO Figure, ON Figure, Rotated ON Figure
Bottom Line: Rotated BxA Figure, X-Sec through Mineral & Skiodrome, Vibration directions showing constructive (blue in center) and destructive (yellow on sides) interference colors

BxA=Acute Bisectrix Figure
BxO=Obtuse Bisectrix Figure
ON=Optic Normal or Flash Figure
OA=Optic Axis
Biaxial Minerals
How to determine optic sign from a BxA Figure
Biaxial Crystals

How crystallographic directions correspond to optical data
Examples of BxA Figures (through rotation angles)
1- Thin Muscovite (low 2V)
2- Thick Muscovite (low 2V)
3- Topaz (higher 2V)
4- Biotite (low 2V)
Example of Optic Axis Figure (OA) through rotation Hornblende (slightly off center)

Note that the isogyre stays in the field of view and just rotates.