GY 302: Crystallography & Mineralogy

Lecture 7a: Optical Mineralogy
(two day lecture)

Instructor: Dr. Douglas Haywick
This Week’s Agenda

1. Properties of light
2. Minerals and light transmission
3. Minerals properties under PPL (Plane polarized light)
4. Mineral properties under XN (crossed Nichols/polars)
Identification of rocks and minerals in hand specimen is one of the important skills that all geology students need to learn. But even the best geologists are limited in the number of substances that they can ID.
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Enter microscopy…

… many characteristics that are apparent in hand specimen can be more diagnostic at microscopic scales.
Optical Mineralogy

But in order to do optical mineralogy and thin section petrography, you first have to understand basic properties of light.
Light

• Light is a propagating wave front that moves fast.

• The velocity of light in a vacuum is one of the most important constants in science:

$$V_c = 2.988 \times 10^8 \text{ m/s}$$

(this constant is usually designated $C$)
Light

• When light travels from one medium to another (vacuum to air, air to water), interesting refraction effects occur.

The **Index of Refraction** \((n)\) of a material is a ratio of \(C\) to the speed of light through a material \((V_x)\).

\[ n_x = \frac{C}{V_x} \]
The Index of Refraction is one of the most diagnostic properties of a substance...including minerals

<table>
<thead>
<tr>
<th>Material</th>
<th>$n_x$</th>
</tr>
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<tbody>
<tr>
<td>air</td>
<td>1.000027</td>
</tr>
<tr>
<td>Water (20 °C)</td>
<td>1.333</td>
</tr>
<tr>
<td>glass</td>
<td>1.50</td>
</tr>
<tr>
<td>minerals</td>
<td>1.40-3.22</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mineral</th>
<th>$n_x$</th>
</tr>
</thead>
<tbody>
<tr>
<td>fluorite</td>
<td>~ 1.435</td>
</tr>
<tr>
<td>leucite</td>
<td>~ 1.510</td>
</tr>
<tr>
<td>Canada balsam</td>
<td>~ 1.535</td>
</tr>
<tr>
<td>quartz</td>
<td>~ 1.545 ($n_o$)</td>
</tr>
<tr>
<td>apatite</td>
<td>~ 1.635 ($n_o$)</td>
</tr>
<tr>
<td>augite</td>
<td>~ 1.71 ($n_β$)</td>
</tr>
<tr>
<td>zircon</td>
<td>~ 1.95 ($n_o$)</td>
</tr>
<tr>
<td>rutile</td>
<td>~ 2.6 ($n_o$)</td>
</tr>
</tbody>
</table>

http://www.mineralatlas.com/Optical%20crystallography/relief.jpg
Light

• **Dispersion** is the prism effect that occurs when white light is split up into its component colors (i.e., different wave lengths travel at different speeds).
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This is a problem when trying to measure $n_x$ which is why we use monochromatic light.
Light produced from an incandescent source (AKA light bulb) is emitted as waves that have no preferred vibration direction. This too is a complication in optical mineralogy.
In order to do petrography, you need to restrict the light that passes through your mineral specimens to waves that vibrate in a single direction. This is done with the help of a polarizing lens:
Minerals and Light

There are 3 optical classes of minerals:
A) **Transparent** (minerals that transmit light and images)
B) **Translucent** (minerals that only transmit light)
C) **Opaque** (minerals that do not transmit light at all)
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Optical microscopy/thin-section petrography studies transparent and translucent minerals. The vast majority of minerals fall within these classes. Even minerals that you might at first think are opaque (pyroxene, biotite) are translucent if they are sliced thinly enough.
Minerals and Light

• The way that light travels through minerals depends on their crystalline structure.

• Recall the seven crystal systems that caused you so much hell earlier this semester.

Source: www.iit.edu
For minerals in the cubic system, light is transmitted equally (in velocity or wavelength) in all directions through the crystal.

The index of refraction is also uniform in all directions. These minerals are said to be **isotropic**.

Source: www.iit.edu
• All other minerals are termed **anisotropic** and have a **preferred orientation** where light travels faster than in other directions.
Isotropic minerals have a single index of refraction

\[ n_a = n_b = n_c = n \]

\( a = b = c \)

\( \alpha = \beta = \gamma = 90^\circ \)

cubic
Minerals and Light

• Anisotropic minerals two or three indices of refraction

\[ a = b \neq c \]
\[ \alpha = \beta = \gamma = 90^\circ \]

\[ n_a = n_b \neq n_c \]
In order to better visualize how light travels through minerals, geologists came up with the concept of the indicatrix.

The indicatrix is an imaginary object that is defined by the indices of refraction. For isotropic minerals, it is spherical. For anisotropic minerals, it is an ellipsoid.
In order to better visualize how light travels through minerals, geologists came up with the concept of the **indicatrix**.

The longest direction of the ellipsoid is its major axis. The shortest direction, perpendicular to the major axis, is called the minor axis. Perpendicular to the major and minor axes is the intermediate axis. These three axes are called the **principal axes**.
Minerals and Light

Isotropic Minerals are easy

Cubic Class

\[ a = b = c \]

Crystallographic axes.

Spherical indicatrix.

\[ Ma = Mb = Mc \]
Anisotropic Minerals come in 2 flavors:

1: **Uniaxial** \((n_x = n_y \neq n_z)\)

Tetragonal/Hexagonal/Trigonal Classes
Anisotropic Minerals come in 2 flavors:

2: **Biaxial** \((n_x \neq n_y \neq n_z)\)
Minerals and Light

Now it gets complex.
Minerals and Light

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• All anisotropic minerals divide polarized light into two rays which vibrate in mutually perpendicular planes.
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• One of the rays has a constant velocity regardless of the light path (ordinary ray or o-ray).
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• All anisotropic minerals divide polarized light into two rays which vibrate in mutually perpendicular planes.

• One of the rays has a constant velocity regardless of the light path (ordinary ray or o-ray).

• The other ray is called the extraordinary ray (or e-ray) and its velocity varies with direction.
In the same way that we can use the indicatrix to portray the various indices of refraction for the mineral classes, it is possible to construct a graphic image summarizing the velocity and vibration direction differences of the o- and e-rays.
Minerals and Light

• This splitting of the o-ray and e-ray as it passes through a material is known as **double refraction** (or **birefringence**)

http://plc.cwru.edu
• All anisotropic minerals have some component of double refraction, but it is especially pronounced in optical calcite (or Icelandic spar).
Minerals and Light

• Try doing this with Iceland Spar
There is only one orientation where the velocity of the o-ray and the e-ray is the same (the places where the circle and the ellipse meet). This orientation is called the **optic axis** and this is the only direction where double refraction does not occur.
Minerals and Light

- In many minerals, the optic axis has the same orientation as the c (or z) axis of a crystal. In these situations, anisotropic minerals mimic isotropic minerals under a microscope (pseudo-isotropic).
Today’s Stuff To Do

1. Take home Lecture test 1 issued
   (due next Tuesday; 11:00 AM)

   NO ONLINE LECTURE THIS WEEK

Today’s Lab

1. Quiz 2 (Orthorhombic/Tetragonal models 12:00 -12:20 PM)
2. Assignment 4: (Monoclinic and Triclinic models) Issued