Lecture Notes - Optics 6: Measurement of $\mathbf{n}_\varepsilon$ and $\mathbf{n}_\omega$, Spindle Stage

- The variation of the velocity of light with vibration direction in uniaxial minerals can be fully characterized by determining just two refractive indices, $\mathbf{n}_\varepsilon$ and $\mathbf{n}_\omega$. These two indices may be determined using oils and Becke line tests in a manner similar to that used for isotropic minerals. However, care must be taken to select and orient the grain being tested so that the results of the Becke line test are meaningful.

- If an anisotropic mineral is at extinction, then one of its two principle vibration directions is parallel to the (E-W) polarizing filter. All of the light passing through the crystal is then vibrating along the (now E-W) principle direction. Therefore, a Becke line test on a mineral at extinction will measure the refractive index for the principle vibration direction oriented E-W. If the crystal is then rotated 90° to the next extinction position, a Becke line test may be performed on the other principle vibration direction (now oriented E-W).

- For a uniaxial crystal of random orientation, the two principle vibration directions have refractive indices $\mathbf{n}_{\varepsilon'}$ and $\mathbf{n}_\omega$. This means that a crystal with its **c**-axis in any orientation may be used to measure $\mathbf{n}_\omega$. However, $\mathbf{n}_\varepsilon$ can be determined **only** if the **c**-axis is horizontal, so that one of the principle refractive indices is $\mathbf{n}_\varepsilon$ (*i.e.* $\mathbf{n}_{\varepsilon'} = \mathbf{n}_\varepsilon$). Thus, for uniaxial minerals Becke line tests should always be performed on crystals with their **c**-axis horizontal.

- A uniaxial mineral with its **c**-axis horizontal will exhibit the maximum retardation Δ possible for that mineral (at constant thickness). Therefore, to measure $\mathbf{n}_\varepsilon$ and $\mathbf{n}_\omega$ the procedure to follow is:

  (a) Determine whether the mineral is uniaxial positive ($\mathbf{n}_\varepsilon > \mathbf{n}_\omega$) or unaxial negative ($\mathbf{n}_\varepsilon < \mathbf{n}_\omega$).
  (b) Identify the mineral grain on your slide with the maximum retardation.
  (c) Confirm that the **c**-axis is horizontal by checking for a flash figure.
  (d) Rotate the stage until the grain is at extinction (between crossed polars).
  (e) Perform a Becke line or oblique illumination test (in plane polarized light).
  (f) Rotate the stage 90° to the next extinction position.
  (g) Perform a Becke line or oblique illumination test (in plane polarized light).

  In general, both $\mathbf{n}_\varepsilon$ and $\mathbf{n}_\omega$ will be above or below the refractive index of the oil being used and the procedure is repeated with an appropriately higher or lower index oil. Eventually, an oil will be found that has a refractive index between $\mathbf{n}_\varepsilon$ and $\mathbf{n}_\omega$. If the mineral is positive, then $\mathbf{n}_\varepsilon$ will be the high index and $\mathbf{n}_\omega$ the low index. If the mineral is negative, $\mathbf{n}_\omega$ will be the high index. At this point, $\mathbf{n}_\varepsilon$ and $\mathbf{n}_\omega$ must be pursued individually until a match is obtained. Because δ is low for many minerals, $\mathbf{n}_\varepsilon$ and $\mathbf{n}_\omega$ will typically be similar in value. Because the optic sign is known, the quartz plate may be used to identify $\mathbf{n}_\varepsilon$ and $\mathbf{n}_\omega$.

- A **spindle stage** is a device designed to enable you to rotate a mineral grain about an axis that is perpendicular to the rotation axis of your microscope. A uniaxial mineral grain mounted on a spindle stage can always be oriented so that its **c**-axis is horizonal. When the spindle position that makes the **c**-axis horizontal is discovered, Becke line tests can be performed as outlined above. However, use of the spindle stage has the distinction that the oils are changed, but not the crystal (it's glued to the spindle!).

- To find the **spindle position** that makes the **c**-axis horizontal, it is first necessary to find the **stage position** that makes the spindle E-W. The following steps are required to orient the spindle E-W (see Bloss p.20):

  (a) Set the spindle position to 0° (**S**=0°)
  (b) Identify a stage position with the spindle approximately E-W (~$\mathbf{M_R}$).
  (c) Rotate the stage **clockwise** until the crystal is extinct. Record the stage position ($\mathbf{M_0}$).
  (d) Return the stage to where the spindle is approximately E-W (~ $\mathbf{M_R}$).
  (e) Set the spindle position to 180° (**S**=180°).
  (f) Rotate the stage **anticlockwise** until the crystal is extinct. Record the stage position ($\mathbf{M_{180}}$).
  (g) Calculate the exact E-W position ($\mathbf{M_R}$) from the equation:

$$M_R = \frac{M_0 + M_{180}}{2}$$

  (h) Rotate the stage to position $\mathbf{M_R}$.

- With the spindle oriented E-W, it is now easy to find the spindle angle (**S**) that makes the **c**-axis horizontal.

  (a) Rotate the **spindle** until the crystal becomes extinct. At this point, the **c**-axis **must** be oriented in the vertical E-W plane.
  (b) Record the spindle angle ($\mathbf{S_V}$).
  (c) Rotate the spindle 90° to ($\mathbf{S_V}$+90°) or ($\mathbf{S_V}$-90°) and the **c**-axis will be horizontal!