

## OLIVINES, PYROXENES, AND AMPHIBOLES PLEOCHROISM, INTERFERENCE COLORS AND EXTINCTION ANGLES

### Pleochroism

When minerals are viewed under PP they may show color. Many minerals are transparent at the standard thickness of a thin section (30 microns). The absence of color is not reported. The presence of color should be reported. This color is a natural color. Some minerals show different colors when viewed in different directions (such as by rotating the stage). This phenomenon is known as pleochroism (literally meaning many colors). Sometimes the color remains the same but the intensity of absorption of light changes. This is an absorbency phenomena but may be difficult to separate from pleochroism. For pleochroic minerals the observed color range should be reported. For example, inky blue to dark brown or colorless to light yellowish-green.

### Interference Colors

All non-isotropic minerals display the property of birefringence. The ordinary and the extraordinary rays vibrate at right angles to each other and will therefore experience different indices of refraction. This implies that the two rays travel at different velocities and that they will no longer be in phase after emerging from the crystal. This produces destructive interference at certain wavelengths, constructive interference at other wavelengths. The various interferences produce **interference colors**. The thickness of the crystal also is important in determining what interference colors are observed. At a standard thickness of 30 microns certain interference colors are characteristic of certain minerals and can help to determine the identity of unknown minerals. Interference colors are seen only in crossed-nicols.

To observe interference colors place the quartz wedge compensator into the compensator slot. Be sure to observe under CN. Slowly insert the compensator and view the resulting colors. As the compensator is inserted you should see several repetitions of the spectrum (remember ROY G. BIV). Each repetition is an **order** of interference colors. You should be able to observe between 4 and 6 orders depending on the compensator. Notice that fourth order and higher are pastel colors. The various orders of interference colors are denoted 1° (first order), 2° (second order), etc. We seek to determine the highest order interference color in a given mineral. Highest order refers to the color with the highest number and within an order **red** is the highest color, **blue** the lowest. Thus 2° **red** is higher than 2° **blue**, but 3° **blue** is higher than 2° **red**. Compare what you see in the microscope to the Michel-Levy color in the laboratory.

To determine the order of the observed interference colors we may proceed in two ways. We could compare the observed colors to the Michel-Levy color chart. Unfortunately the color reproduction of these charts is generally totally inadequate for this method to be of use. A better method is to use the charts in conjunction with the 1° **red** and quarter- $\lambda$  accessory plates. The 1° **red** plate has a retardation of 550 nm. The quarter- $\lambda$  plate has a retardation of 150 nm.

**Example:** Suppose a mineral is observed in CN. We see a **yellow** interference color but are unsure whether it is 1°, 2°, or 3°. The mineral should be observed in the 45° off extinction position because the colors are brightest and easiest to see in this position. We insert a 1° **red** accessory plate and observe and record the resulting color. We might see another **yellow** color, somewhat paler than the original color. We rotate the stage 90° and observe the new color. It is a **yellow-orange** color, less intense than the original color. We must now interpret these results. We know that one color corresponds to addition and the other to subtraction, but are unsure which is which.

**1st possibility:** Original color = 1° **yellow** (~ 350 nm)

$350 + 550 = 900 \text{ nm}$  The M-L chart shows that 900 nm corresponds to 2° **yellow**

$|350 - 550| = 200 \text{ nm}$  or 1° **white**

This is clearly not what we observed.

**2nd possibility:** Original color = 2° **yellow** (~ 925 nm)

$925 - 550 = 375 \text{ nm}$  (1° **yellow-orange**)

$925 + 550 = 1475 \text{ nm}$  (3° **yellow**)

This seems to correspond to what we see. However to be sure we calculate a third case.

**3rd possibility:** Original color = 3° **yellow** (~ 1500 nm)

$1500 - 550 = 950 \text{ nm}$  (2° **yellow-orange**)

$1500 + 550 = 2050 \text{ nm}$  (4° pastel **pink**)

Since the **pink** color does not match our observation we conclude the original color was 2° **yellow** and that the first position we used with the accessory plate was the addition position. For your laboratory exercise estimate interference colors and test your estimates whenever possible by using the accessory plates. The quarter- $\lambda$  plate is used in the same except that we add or subtract 150 nm instead of 550 nm. The interference color observed for a particular grain will depend on the orientation of the grain. We seek to determine **the** birefringence, not just any birefringence. Therefore we try to observe the highest color a particular mineral shows. This may, at first, involve looking at a number of grains in a thin section.

Once the highest order color is determined we can use the M-L chart and the knowledge that thin sections are 30 microns thick to estimate **the** birefringence. Many charts also show minerals which might produce these colors along the margin. Mafic minerals such as olivine, pyroxene, and amphibole generally produce "high", meaning more than first order, interference colors. In lab 5 you observed feldspars and saw that they were usually **white** or **gray** in CN. These were first-order colors. Unusually thick feldspars in the grain mounts might show 1° **yellow** colors.

## Extinction Angle:

Non-isotropic substances will go into extinction (show 1° black interference colors) four times as the stage is rotated in a full circle, or once every ninety degrees. Frequently a grain will have a prominent linear feature which can serve as a reference line. Such linear features are generally either crystal faces or the lines of intersection of cleavage planes with the crystal plate surface (the latter are called cleavage traces). In order to observe extinction angles set the microscope for CN observation. Align the crystal direction with one of the cross-hairs by rotating the stage. The angular position of the microscope stage is determined by noting the angle indicated at the index mark. The stage is rotated until the nearest extinction position is reached and the angular position is again noted. The difference between the two readings is an extinction angle, tau ( $\tau$ ).  $\tau$  should always be  $\leq 45^\circ$ . If  $\tau$  exceeds  $45^\circ$  rotate the stage in the other direction and recompute the extinction angle.

There are three general classes of extinction, as follows:

1) Parallel extinction: The crystal direction is parallel to the cross-hair at extinction.  $\tau = 0^\circ$ . (See Nesse, pp. 44-48) Also called straight extinction. Not possible in triclinic crystals.

2) Symmetric extinction: When a crystal shows two crystal directions (such as cleavage traces) the extinction position may bisect the angle between the crystal directions.  $\tau \neq 0^\circ$ . Not possible in triclinic crystals.

3) Inclined extinction: A single crystal direction will not be parallel to a crosshair at extinction. This can occur only in biaxial crystals.  $\tau \neq 0^\circ$ .

Since grains are randomly oriented in a thin section (unless a section is specially prepared and/or foliation is present in the rock) it is possible to obtain different extinction angles for the same mineral in the same section. However, there is a maximum value that is possible for any mineral. The approximate maximum value may be determined by taking a series of readings on the same mineral and reporting **only** the highest extinction angle observed for any given mineral. Enough readings should be taken so that a good approximation to the maximum angle is obtained.

## **Olivines:**

The olivines form a complete solid solution series from forsterite ( $\text{Mg}_2\text{SiO}_4$ ) to fayalite ( $\text{Fe}_2\text{SiO}_4$ ). Forsterite is colorless to light yellow in this section (this is the true color observed in PP light). Fayalite may be colorless to yellow. Simple twinning may be present in iron-rich olivines. The cleavage, if present, is only fair to poor. Peridot denotes a gem-quality olivine. Peridot crystals are generally larger than other specimens.

Examine the following olivine thin sections. Be sure to estimate the highest order interference color present. Because clear reference directions may be absent it may not be possible to estimate extinction angles. The specimens are color-coded **blue**.

1. Olivine - One twin is present, as is some cleavage. Some crystals may show undulatory extinction.

41- This a sample of dunite, an ultramafic rock containing 90+% olivine, with a few other crystals, mostly plagioclase.(label is red numbers on white background)

### **Pyroxenes:**

Pyroxenes may be orthorhombic or monoclinic. The extinction type for orthopyroxenes is parallel, whereas for clinopyroxenes it is generally inclined. Cleavage (good or perfect) is often present at angles of about  $87^\circ$  or  $93^\circ$ . The cleavage is on {210} for orthopyroxenes and {110} for clinopyroxenes. Twinning occurs in the clinopyroxenes. The specimens are color-coded **green**.

Examine the following sections.

44-4163 - Enstatite Prominent cleavage parallel to length of crystal

6. Diopside - Slight pleochroism (variation of color as viewing angle is changed in PP).

9. Augite in scapolite - Some impurities, but the major mineral is augite. Examine the slide carefully looking for cleavage in 2 directions. What is the angle between the cleavage planes?

### **Amphiboles:**

Amphiboles may be orthorhombic or monoclinic. The extinction type for orthoamphiboles is parallel, whereas for clinoamphiboles it is generally inclined. Cleavage (good or perfect) is often present at angles of about  $54-56^\circ$  or  $124-126^\circ$ . The cleavage is on {210} for orthoamphiboles and {110} for clinoamphiboles. Simple twinning parallel to [100] is fairly common in amphiboles. Most amphiboles show moderate to strong pleochroism. Amphiboles often display elongated prismatic habits and may be fibrous or splintery. They are sometimes asbestiform. Less commonly they may be stubby prisms. Crystals may be four or six-sided in thin section.

Examine each of the following amphibole thin sections. The specimens are color-coded **orange** for the amphibole thin section set.

1. Anthophyllite - Light tan in PP but often showing bright interference colors in CN. Crystals often elongated. There are also crystals of Talc in the slide. They show very high interference colors in CN, but are colorless in PP. The natural color of the anthophyllite here indicates it has some iron mixed in it.

8. Hornblende - Pseudo-hexagonal cross-section on some grains. Some grains are extremely pleochroitic. Many are quite dark, making observations difficult.

10. Glaucophane - A soda amphibole. The crystals are elongated and intergrown. Shows a blue to violet color in some orientations.

20. Crocidolite - Asbestiform habit is apparent. Mixed with felsic layers (mainly quartz). NOTE: Examine this, but you do not need to report it on the answer sheet.

23. Tremolite (with garnet) - A few good examples of simple twinning are present in larger crystals. Note the cleavage (what is the cleavage angle?) The primary cleavage is good, and easily seen. The secondary cleavage is only fair, and is harder to see.

### **ASSIGNMENT:**

You should prepare a **sketch** from 1 of the **olivine** sections, 1 of the **pyroxene** sections, and two of the **amphibole** sections. Label each sketch and describe what you are seeing. Complete the table on the data sheet for the properties of all slides except tremolite (with garnet) and crocidolite. If you cannot perform a measurement, you should write ND (no data) in the box.

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