

## OPTICAL PROPERTIES OF ORE MINERALS IN POLISHED SECTIONS

The optical properties of ore minerals determinable under the microscope fall under two categories:

1. *Properties observed in plane polarized light* (without analyzer). These include color, reflectivity, bireflectance (= absorption, pleochroism or reflection pleochroism).
2. *Properties observed between crossed nicols*. These include isotropism vs. anisotropism, polarization colors and internal reflections. Besides these, other rotation properties viz., polarization figures and phase differences may be determined.

**Color:** Most ore minerals have colors ranging from pure white to gray, and only a few have definite tints of the spectral colors. The human eye has a poor memory for colors but at the same time it has a marvelous sensitivity to very slight differences in hue or brightness of adjacent objects. The apparent color of a mineral as seen under the microscope depends upon a number of factors, and as such is of limited diagnostic value by itself. Factors affecting the apparent color of a mineral are:

1. Color of surrounding minerals.
2. Perceptions.
3. Type of illumination.
4. Tarnishing and incorrect polishing.
5. Index of refraction of the immersion medium.

**Reflectivity:** is the ratio of the intensity of light reflected by a mineral to the intensity of the light incident upon it, expressed in per cent (R or R%). Reflectance of minerals varies as a function of the following:

1. Crystallographic orientation of the polished surface relative to the vibration directions of linearly polarized incident light.
2. Wavelength of light.
3. Angle of incidence.
4. Degree of polish.

Quantitative reflectance measurements are done with various types of photometers, but rough visual estimates may be made and minerals in a section may be arranged in an order of increasing or decreasing reflectance. Eg. Quartz (5%), magnetite (20%), galena (43%), pyrite (55%).

**Bireflectance:** Most minerals of the non isometric groups show changes in reflectance or color (or tint) or both when sections of certain orientations are rotated. These properties are collectively termed bireflectance. In some literature, bireflectance refers only to change in reflectivity and reflection pleochroism is the term used to describe a change in color. All sections of the cubic minerals and basal sections of the hexagonal and tetragonal crystals do not exhibit these properties. In addition to noting this property it is usual to note the intensity (e.g. very strong, strong, moderate, weak, very weak) with which these properties are exhibited. The following are some examples of bireflecting minerals:

- Strong - graphite, molybdenite, covellite, stibnite, valleriite.
- Moderate - marcasite, hematite, niccolite, cubanite, pyrrhotite.
- Weak - ilmenite, enargite, arsenopyrite.

Weak or very weak bireflectance in minerals may be identified by closely observing adjacent grains.

**Anisotropism:** Polished sections of non-isotropic minerals when rotated through 360° under 'crossed' nicols will show either a) complete darkness, or b) faint illumination with no change in intensity or color of illumination. Such minerals are termed isotropic. Minerals crystallizing in the non-isometric systems will show a change in the intensity of illumination or color of illumination (or both) in white light. Such minerals are termed anisotropic. Sections of certain special orientations of anisotropic minerals (e.g. the basal sections of hexagonal and tetragonal crystals) may be isotropic. As with pleochroism, the anisotropy can range from a maximum to zero depending upon the orientation of the section, and therefore the terms very weak, weak, moderate, strong and very strong are used to describe it. Anisotropy is best observed under intense illumination using a plane glass reflector and a low power ocular. In cases of weak anisotropy, the effects may be detectable only when a number of adjacent grains of a mineral are minutely examined while rotating the stage. Observation of anisotropy may be more easily accomplished by either a) throwing the analyzer slightly off from the precise crossed position, or b) leaving the stage stationary and slowly rotating the analyzer 5-10° back and forth through its crossed position.

NOTE: Fine parallel scratches of improper polishing or careless buffing can produce effects similar to pleochroism and anisotropy

**polarization colors:** The change in color of a mineral during rotation under crossed nicols produces a beautiful effect. These are the polarization colors. The polarization colors of certain minerals are highly characteristic and extremely useful in identification. However they are used less than they deserve to be for several reasons:

- ° The colors are constant only if the nicols are precisely crossed, which is rarely the case.
- ° Polarization colors appear different to different observers, hence the difficulty in applying precise color terms.
- ° The intensity and hue of polarization colors varies from microscope to microscope.
- ° Constant illumination is necessary for consistent results.

**Internal Reflections:** Translucent minerals, when observed under reflected light, allow light to penetrate beneath the surface and be reflected back to the observer from cracks, crystal boundaries, cleavages and other flaws within the crystal. Such light will appear as diffuse areas or patches known as internal reflections. Although visible in plane polarized light, internal reflections are best seen under crossed nicols and intense illumination using oil immersion and high power magnification. They are best seen at the edges of grains or in fine grains. It is important to note that many grains of a mineral that could show internal reflections may not exhibit them. Both the occurrence and colors of internal reflections are of diagnostic value. The following are some examples:

Sphalerite Yellow to brown (sometimes red to green)

Cinnabar Blood red

Proustite-pyrargyrite Ruby red

Rutile Clear yellow to deep red-brown

Anatase Blue

Azurite Blue

Malachite Green  
Cassiterite Yellow brown to yellow  
Hematite Blood red  
Wolframite Deep brown  
Chromite Very deep brown

## PHYSICAL PROPERTIES OF ORE MINERALS IN POLISHED SECTIONS

The physical properties of ore minerals observed in polished sections are of great assistance in mineral identification, and hence their study is routine in ore microscopy. The most useful and easily observable physical properties are crystal form and habit, cleavage and parting, twinning, zoning, inclusions and intergrowths and hardness.

**Crystal Form and Habit:** Some ore minerals, particularly the harder ones viz., pyrite, hematite, wolframite, arsenopyrite, cobaltite and magnetite have a remarkable power of crystallization and develop well formed crystals even under adverse conditions. The softer minerals, e.g. chalcopyrite, galena, tetrahedrite and pyrargyrite have somewhat lower powers of crystallization and form crystals only in open spaces. Since a polished surface shows two dimensional sections rather than whole crystals, the shape as seen in a polished section depends upon the manner the crystal is intersected by the polished surface. Thus cubes appear rectangular or triangular of various shapes; hexagonal prisms appear hexagonal or rectangular, etc., so that the crystal form must be mentally reconstructed from observations of a number of crystals of a particular mineral.

Terms used in mineralogy e.g. cubic, octahedral, acicular, radiating, columnar, bladed, tabular, foliate, micaceous, concentric, colloform, prismatic, fibrous, etc. are appropriate for describing crystal form and habit as seen in polished sections.

**Zoning:** Many ore minerals exhibit zonal growth in the form of concentrically shelled structure indicating deposition in successive layers around a nucleus. The shells may be few or many and thin or thick. Zoning is sometimes visible in ordinary light due to color contrasts, physical discontinuities or zonally arranged inclusions. In other cases zoning is visible only in crossed nicols or after etching with an appropriate chemical. Zoning in minerals is due to either of the following reasons:

1. Pauses in deposition
2. changes in the rate of growth
3. Simultaneous crystallization of more than one mineral at certain stage / stages.
4. Variation in the composition of successively deposited layers.

Galena, sphalerite, pyrite, stibnite, cobaltite, safflorite and arsenopyrite are some of the many minerals that show zonal structure.

**Cleavage and Parting:** In polished surfaces the cleavages of minerals are not as well developed as in thin sections. Cleavage or parting is evident in the form of one or more sets of parallel, distinct or indistinct cracks. Minerals may exhibit one to three sets of cleavages depending upon the number of sets present and the orientation of the polished surface with respect to these. The presence of three or more sets of cleavages may give rise to triangular pits usually arranged in rows parallel to one set. Such pits are characteristic of galena, and may also be present in magnetite, pentlandite, gersdorffite, etc. A prismatic cleavage gives rise to diamond-shaped, triangular or rectangular patterns; a pinacoidal cleavage gives rise to a set of parallel cracks.

Cleavage of a mineral may not be evident in a well polished surface, or in minerals occurring in fine grained aggregates. It is likely to be more evident in slightly weathered ores, during the earlier stages of polishing, at the margins of grains, or after etching.

**Twinning:** Three major types of twinning may be observed in ore minerals seen in polished sections - growth, inversion and deformation. Twinning is best seen in anisotropic minerals under crossed polars. In isotropic minerals it is generally not visible unless the surface is etched. It is sometimes evident from abrupt changes in the orientation of cleavages or of rows of inclusions. The crystallographic planes involved in twinning are usually not determinable in polished sections. Nevertheless, the twin patterns in some minerals are quite characteristic e.g. "arrowhead" twins (growth) in marcasite, lamellar twins (deformation) in hematite and chalcopyrite and "oleander leaf" twins (inversion) in chalcopyrite, stannite and acanthite.

**Inclusions and Intergrowths:** Inclusions of one or more minerals in another is a very common feature of ores. The characteristics of inclusions depends to some extent on the mode of formation of the guest and the host. They may have either of the following modes of formation:

1. Grains of a mineral accidentally included during growth of the host.
2. Remnants of a pre-existing mineral that was replaced by the host.
3. Result from simultaneous deposition of a mineral with the host.
4. Products of breakdown (exsolution) of a solid solution into two components.

In so far as the mode of occurrence is concerned, inclusions may:

1. Occur singly or in groups
2. Be regular (signifying a control of crystallographic planes of the host over the guest) or highly irregular in shape.
3. Be large or very minute (submicroscopic).
4. Be evenly (signifying control of crystallographic planes of guest on the growth of host) or unevenly distributed through the host.
5. Being abundant in certain bands, signifying a zonal growth structure of the host.

Intergrowths refer to simultaneous deposition of one mineral with another. The term also covers graphic and subgraphic arrangements of two minerals, or exsolutions in which the two minerals are intimately associated and neither can be said to be the host. A knowledge of inclusions is useful in deciphering the paragenetic sequence while that of intergrowths in identification since the number of mineral combinations is limited. This is particularly true of exsolution intergrowths.

**Hardness:** The term hardness as used in ore microscopy refers to a number of phenomenon. Three types of hardnesses are particularly important - polishing, scratch and microindentation. It is important to note that these three forms are not entirely equivalent, being the response to different kinds of deformation or abrasion. Only the polishing hardness shall be discussed here.

Polishing hardness is the resistance of a particular mineral to abrasion during the polishing process. The fact that hard minerals are worn away more slowly than soft minerals means that they may stand slightly above the surface of softer grains giving rise to an effect called "polishing relief".

Polishing hardness can be examined under a standard ore microscope by comparing the relative hardness (i.e. relief) of adjacent phases and can be very helpful in mineral identification. The determination involves a simple test using the Kalb light line, a phenomenon analogous to the Becke line used in transmitted light. The procedure is as follows:

1. Focus on a clear boundary between two mineral grains.
2. Close the aperture diaphragm partly.
3. Raise the microscope tube slowly so that the sample begins to go out of focus as the tube is gradually raised.
4. Observe the "line" of light which will move from the boundary towards the softer mineral, provided there is appreciable relief.