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Scope

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Genesis of Minerals

Composition of the Earth’s Crust

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Study of Minerals with Emphasis on Rock-forming Minerals

Physical Properties of Minerals

Minerals may be studied and identified by microscope examination, chemical analysis, x-ray diffraction or the electron probe. Implication of these methods requires time and the associated tools are unavailable to most mineralogists or to mineralogy students. Fortunately, the commonly occurring minerals can usually be identified by a study of their physical properties in hand specimen. The physical properties are a direct result of the nature of the elements comprising the mineral, the type of bonding between atoms and the arrangement of ions in the crystal lattice.

Identification of minerals

If a nongeologist is provided with a mineral specimen, generally, the appearance, especially color, would be mentioned first. After a while, he may go on to describe the shape and nature of visible crystals. Pyrite, for example, might be described as being metallic, gold in color, and forming cubic crystals. A piece of rose quartz might be described as being pink, glassy, transparent, and having a hexagonal shape.

The physical properties which we will discuss in some detail and utilize them in the identification of minerals are the following:

- Optical properties
    - Color
    - Diaphaneity
    - Luminescence
    - Luster
    - Streak
- Crystal shape
- Properties regarding strength and breaking of minerals
    - Tenacity
    - Fracture, cleavage and parting
    - hardness
- Density and specific gravity
- Magnetism of minerals
- Electrical properties
- Reaction to acid

Optical properties

Reflection and refraction

When a ray of light in air strikes diagonally on the surface of a nonopaque solid, part of the light is reflected back into the air (the reflected ray) and part enters the solid (the refracted ray). The direction of the reflected ray is governed by the Law of Reflection, which states that the angle of reflection is equal to the angle of incidence and that the reflected and incident rays lie in the same plane. The relationship between the paths of the incident and refracted rays is known as the Law of Refraction, or Snell's Law.

Index of refraction: the ratio of the sine of the angle of incidence to the sine of the angle of refraction.

$$n = \frac{sin\theta_1}{sin\theta_2}$$

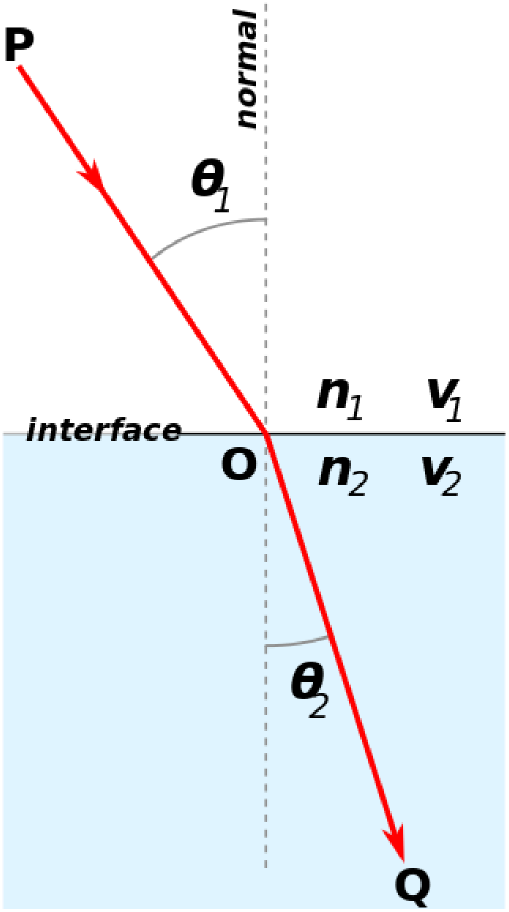

Figure 1: Illustrates Snell's law

It was later proved that the index of refraction is is also the ratio of the velocity of light in the air to the velocity of light in the solid, so that if V_1 is the velocity light in air, V_2 the velocity of light in the solid, then

$$n = \frac{V_1}{V_2}$$

The velocity of light in the air is 300,000Km/s. Most solids have refractive indices of between 1.4 and 2.0.

The refractive index of a substance is related to its chemical composition and crystal structure, just as it its density is; in fact, specific gravity (G) and refractive index (n) may be correlated by the following approximate equation

$$\frac{n-1}{G} = k$$

where k is a constant related to the composition of the substance.

There is also a close connection between optical properties and crystal structure of a solid.

In crystallography, the **isometric** (or **cubic**) **crystal system** is a crystal system where the unit cell is in the shape of a cube. This is one of the most common and simplest shapes found in crystals and minerals.

In isometric and noncrystalline substances, the velocity of light is the same in all directions, and hence the refractive index is the same for all directions; such substances are termed to be optically **isotropic**. In all other substances, the velocity of light varies according to its direction of vibration; such substances are said to be optically **anisotropic**.

A ray of light entering a an anisotropic substance is split into two rays vibrating at right angles to each other, generally travelling with different velocities and thus having different refractive indices. This difference in refractive indices is termed as **birefringence**. It is typically quite small (e.g., for quartz it is 0.009) and essentially unobservable except by instruments.

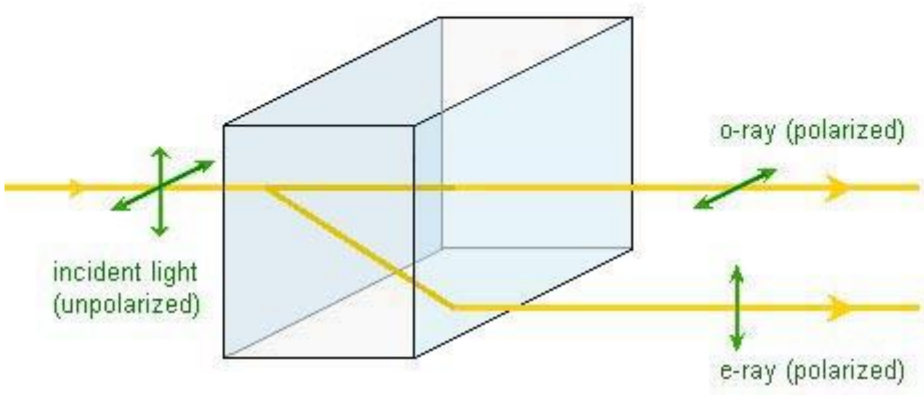

Figure 2: Illustrates the property birefringence.

Color

Color is the most obvious property of minerals. It results partly from the nature of the bonding but chiefly from its chemistry. It may be a property of the pure substance or it may be a result of impurities, present in minute quantities. For some minerals, color is a consistent property and is therefore an aid to identification. For other minerals color is affected by the presence of impurities and may be very variable, e.g. quartz, when pure is colorless but may also be white, brown, pink, violet, grey or yellow due to impurities. Unfortunately color is not a very reliable means of identification.

Color is not a property of a mineral. Instead, the result we observe when light and mineral interact. When we see that something has color, what we are really observing is the color of the light that is reflected or transmitted to our eye. Normal or white light includes many different colors. A mineral will appear white if all of the colors of white light, striking a mineral, are reflected back to our eyes. If none of the colors are reflected back to our eye, the appearance of the mineral will be black.

Metallic minerals, especially sulfides, tend to be constant in their coloration, so mineralogists use color as a key tool for sulfide identification. However, metallic minerals easily tarnish, so a fresh surface is needed to see the true color.

Chemical composition of mineral is the most significant controller of color. Elements that give a mineral its color are called **chromophores**. It does not take large amounts of chromophores to color a mineral. Minor amounts, less than 0.1 wt.% of transition metals such as Fe and Cu, may control a mineral's color because electrons in the *d*-orbitals of transition metals are extremely efficient at absorbing certain wavelength of light. The remaining wavelengths are reflected and give minerals their colors.

If the color of a mineral is due to some essential constituents, it is called **idiochromatic** mineral. The color is constant and predictable in this case. Sphalerite, for example, is an idiochromatic mineral. It changes from white to yellow to brown to black as its composition changes from pure ZnS to a mixture of ZnS and FeS. Many copper minerals are green or blue, while many manganese minerals are pinkish. These colors derive from selective absorption of certain colors by copper and manganese. Their color is also termed “inherent”. This property is often a good aid to mineral identification in hand specimen.

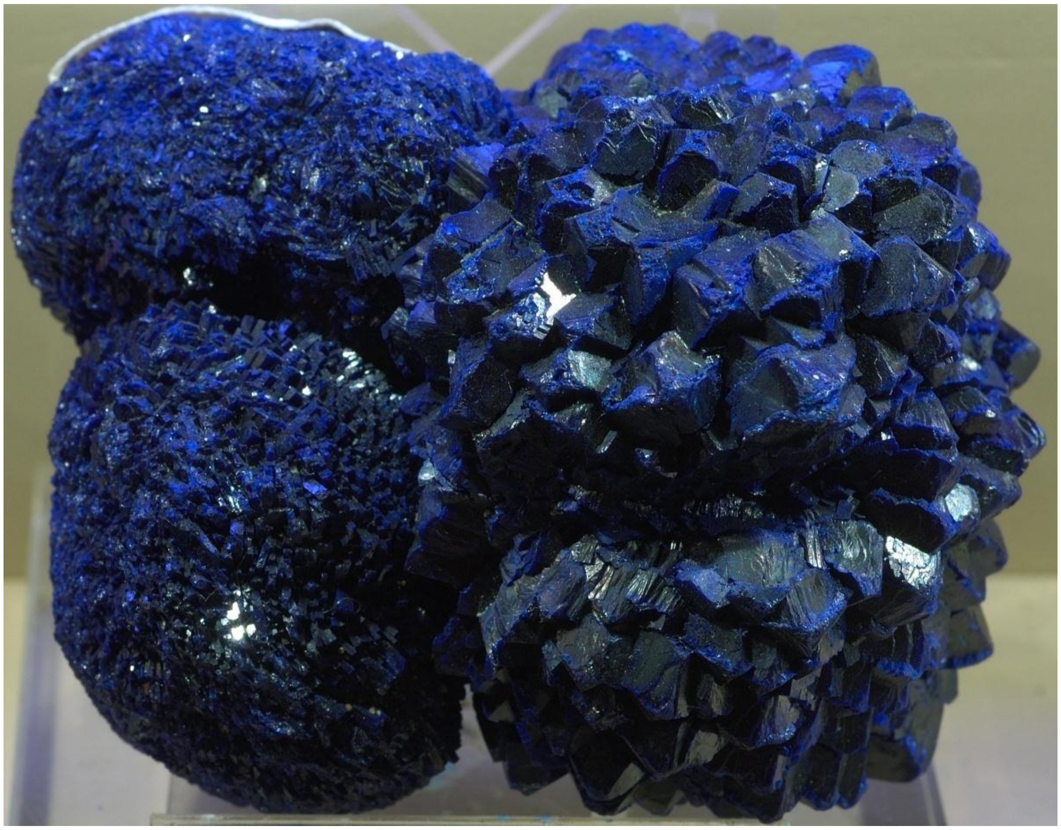

Figure 1: Azurite ($Cu_3(CO_3)_2(OH)_2$); a mineral of idiochromatic characteristic, comprising striking blue color, making it easy to identify by color.

Allochromatic minerals, on the other hand, are those in which minor or trace elements determine the color. Their color may vary from specimen to specimen, which also referred to as “exotic”. This property of a mineral arises due to trace impurities in their composition or defect in their structures. Small amounts of Cr give ruby and some other gemstones deep red colors. Allochromatic Cr is also responsible for the striking green color of emerlald and some tourmilines.

Figure 2: Beryl (Emerald)

Pseduchromatic minerals are those which obtain their color due to diffraction or scattering of light by structure within the mineral. Neither the mineral nor atomic properties are responsible for minerals' colors. Instead, the minerals contain layers (or films) that create light by interference. The color may vary, but it is often a unique property of mineral. For example, precious opal, moonstone, and labradorite all reflect in a characteristic way, but the colors are not true to the types of minerals.

Play of colors

Some minerals are a light show in themselves, actually turning a different color when viewed from different angles under the same light source. This is called **pleochroism**. When only two colors are seen when viewed at different angles, it is called dichroism (also defined as pleochroism of two color components); trichroism indicates three colors. The effect is caused by variable light absorption patterns along different axes of crystals.

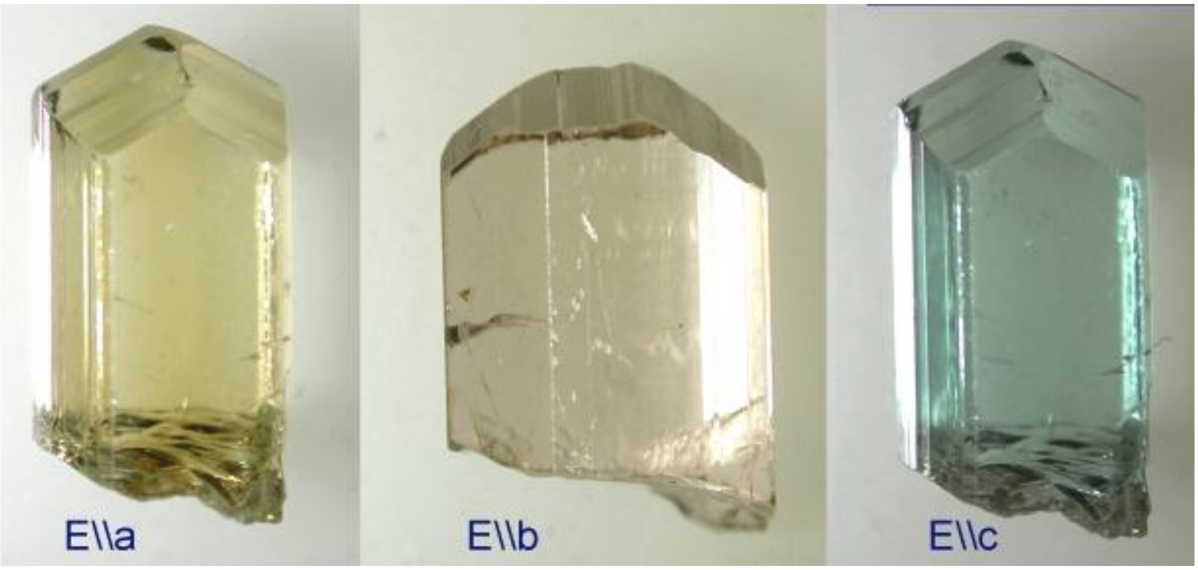

Figure 3: Zoisite mineral showing pleochroism.

Some terms are used to describe special appearances in reflected light. Some of the more frequently used terms are: chatoyancy, iridescence, labradorescence, opalescence, schiller effect etc.

Chatoyancy derived from scattering effects; it is mostly seen in gemmy minerals. Chatoyant minerals show a bright band of scattered light, usually perpendicular to the long direction of a crystal. Such minerals are sometimes said to have a cat's eye (chrysoberyl) or tiger's eye (fibrous quartz) appearance. Chatoyancy is caused by closely packed parallel fibers or inclusions of other minerals within a mineral.

Figure 4: Fibrous quartz showing tiger's eye appearance.

Iridescence is the phenomenon of certain surfaces that appear to change color as the angle of view or the angle of illumination changes. It is often created by structural coloration (microstructures that interfere with light). It is often caused by multiple reflections from two or more semi-transparent surfaces in which phase shift and interference of the reflections modulates the incidental light (by amplifying or attenuating some frequencies more than others). The thickness of the layers of the material determines the interference pattern.

Figuer 5: shows 2 examples of iridescence.

Labradorite can display an iridescent optical effect known as **labradorescence**. The effect is caused by fine compositional layering.

Figure 6: A labradorite mineral showing the effect of labradorescence.

Opalescence is a type of dichroism seen in highly dispersed systems with little opacity. The material appears yellowish-red in transmitted light and blue in the scattered light perpendicular to the transmitted light. The phenomenon is named after the appearance of opals.

Figure 7: a quartz crystal showing opelascence.

Asterism is the display of a star-shaped luminous area. It is seen in some sapphires and rubies, where it is caused by impurities of rutile. It can also occur in garnet, diopside and spinel.

Figure 8: Asterism of a sapphire.

(N.B.: Read more details from your textbook pages of 136-163 and 45-48 of the books Mineralogy (by Berry, Mason and Detrich) and Mineralogy (by Dexter Perkins) respectively.