

## THE COLOR OF MINERALS

When we view mineral specimens, our eyes are drawn to two features: color and form. More often than not, it is color that first attracts our attention. The broad array of mineral color ranges from the intense blue of azurite [basic copper carbonate,  $\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$ ] to the rich yellow of sulfur [native element, S] and the bright red of rhodochrosite [manganese carbonate,  $\text{MnCO}_3$ ]. And the optical mechanics behind the coloration of minerals is as interesting as the colors themselves.

The colors we see in minerals and all other materials are produced by the reactions of the eye and brain to the various wavelengths of light within the visible spectrum. Light waves themselves are not colored. We simply perceive the shortest visible wavelengths as violet, and the longest wavelengths as red.

Light is a form of electromagnetic energy. When white light, which is a mix of all visible wavelengths, strikes a mineral, it is either absorbed, transmitted, or reflected. When a mineral absorbs all wavelengths of white light equally, there is no light remaining to be reflected or transmitted and the mineral appears black. Conversely, a mineral that reflects or transmits all wavelengths equally will appear white or colorless.

Specific colors become apparent when a mineral absorbs only a portion of the wavelengths of the visible spectrum. As an example, azurite absorbs all longer wavelengths except for a narrow band of blue, which it reflects. Rhodochrosite does just the opposite, absorbing the shorter wavelengths and reflecting or transmitting only red. Sulfur absorbs the longest and shortest wavelengths to reflect only the middle range of the visible spectrum—yellow.

The spectral reflectivity, or color, of a mineral is most often determined by idiochromatic or allochromatic mechanisms. In idiochromatic (self-colored) minerals, the light-absorbing atoms are essential parts of the chemistry and crystal structure. An example is rhodochrosite, in which its diagnostic red color is caused by atoms of the essential element manganese.

Many minerals are allochromatic (other-colored), meaning that their colors are caused by traces of impurities called chromophores (color-causing agents). These are non-essential, accessory elements that alter the crystal lattice in ways that cause it to reflect specific colors. When pure, allochromatic minerals are usually colorless or white. But chromophores can create a wide range of colors. Important chromophores include such transition elements as titanium, copper, iron, chromium, nickel, manganese, and vanadium.

An example of an allochromatic mineral is corundum [aluminum oxide,  $\text{Al}_2\text{O}_3$ ]. Pure corundum is colorless. But when such chromophoric elements as chromium, iron, and titanium replace some of the aluminum in the crystal lattice, the reflectivity of the crystal is altered and corundum can become ruby, which is red, or sapphire, which includes every other color.

Light absorption-reflection characteristics can sometimes vary within the same mineral crystal. The pink core and green exterior of “watermelon” tourmaline [elbaite, basic sodium aluminum lithium borosilicate,  $\text{Na}(\text{Al}_{1.5}\text{Li}_{1.5}\text{Al}_6)(\text{BO}_3)_3(\text{Si}_6\text{O}_{18})(\text{OH})_4$ ] is an extreme example of color zoning that results from a change in chemistry during crystal growth. The crystal’s pink core is caused by a manganese chromophore, while the green rind contains an iron chromophore.

In the case of diamond [carbon, C (cubic)] and graphite [carbon, C (hexagonal)], color depends upon crystal structure. Although both consist solely of carbon, diamond is transparent and usually colorless, while graphite is opaque and black. Diamond’s carbon atoms are held together by strong, omnidirectional bonding that facilitates the transmission of light. But unlike

diamond, graphite's carbon atoms are arranged in weakly bonded layers. Because crystal lattices with certain types of weakly bound structures tend to absorb all wavelengths of white light equally, we perceive graphite as black in color.

Hematite [iron oxide,  $\text{Fe}_2\text{O}_3$ ] is another example of how crystal form can influence color. In its macrocrystalline form, hematite is gray-black. But powdered hematite is red to reddish-brown. Hematite and certain other minerals exhibit both "apparent" colors and "streak" colors. Apparent color refers to the color of macro specimens and is determined largely by the nature of the crystal structure. Streak color is the color of the powdered mineral, which consists not of crystals with intact faces, but of randomly oriented particles with irregular surfaces that have very different light absorption-reflection characteristics.

The mineral colors that we perceive are the result of reflection-absorption characteristics that are caused by essential chemical components, the presence of accessory chromophores, the nature of the crystal lattice, or a combination of all three and are one of the most attractive and pleasing features of mineral specimens.

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