

GENERAL OPTICAL CHARACTERS OF MINERALS.

331. There are certain characteristics belonging to all minerals alike, crystallized and non-crystallized, in their relation to light. These are:

1. DIAPHANEITY: depending on the relative quantity of light transmitted.
2. COLOR: depending on the kind of light reflected or transmitted, as determined by the selective absorption.
3. LUSTER: depending on the power and manner of reflecting light.

1. DIAPHANEITY.

332. Degrees of Transparency.—The amount of light transmitted by a solid varies in intensity, or, in other words, more or less light may be *absorbed* in the passage through the given substance (see Art. 307). The amount of absorption is a minimum in a transparent solid, as ice, while it is greatest in one which is opaque, as iron. The following terms are adopted to express the different degrees in the power of transmitting light:

Transparent: when the outline of an object seen through the mineral is perfectly distinct.

Subtransparent, or *semi-transparent*: when objects are seen, but the outlines are not distinct.

Translucent: when light is transmitted, but objects are not seen.

Subtranslucent: when merely the edges transmit light or are translucent.

When no light is transmitted, even on the thin edges of small splinters, the mineral is said to be *opaque*. This is properly only a *relative* term, since no substance fails to transmit some light, if made sufficiently thin. Magnetite is translucent in the Pennsury mica. Even gold may be beaten out so thin as to be translucent, in which case it transmits a greenish light.

The property of diaphaneity occurs in the mineral kingdom, in every degree from nearly perfect opacity to transparency, and many minerals present, in their numerous varieties, nearly all the different shades.

2. COLOR.

333. Nature of Color.—As briefly explained in Art. 294, the sensation of color depends alone upon the length of the waves of light which meet the eye, if they are all of the same length. If the light consists of various wave-lengths, it is to the combined effect of these that the sensation of color is due.

Further, since the light ordinarily employed is essentially white light, that is, consists of all the wave-lengths corresponding to the successive colors of the spectrum, the color of a body depends upon the selective absorption (see Art. 307) which it exerts upon the light transmitted or reflected by it. A yellow mineral, for instance, absorbs all the waves of the spectrum with the exception of those which together give the sensation of yellow. In general the color which the eye perceives is the result of the mixture of those waves which are not absorbed.

All minerals may be divided into two classes: (1) those whose color belongs to the finest particles mechanically made; and (2) those whose color in the state of fine powder is different from what it is in the mass.

To the first class belong the metals and many minerals having a metallic luster; for instance, the powder of the black magnetic oxide of iron, magnetite, is black; that of hematite, which, though often black on the surface, is red by transmitted light, is red, and so on.

To the second class belong the silicates, and in fact the large part of all minerals having an unmetallic luster. With them the color is often quite unessential, being generally due to small admixtures of some metallic oxide, to some carbon compound, or to some foreign substance in a finely divided state. With most of these, the fine powder is either white or light-colored; for example, the streak (Art. 334) of *black, green, red, and blue* tourmaline varies little from *white*.

334. Streak.—The color of the powder of a mineral as obtained by scratching the surface of the mineral with a knife or file, or still better, if not too hard, by rubbing it on an unpolished porcelain surface, is called the *streak*. It is obvious from the distinctions stated above that the streak is often a very important quality in distinguishing minerals. This is especially true with minerals of the first class mentioned above, that is, those with metallic luster, as defined in Art. 338.

335. Dichroism; Pleochroism.—The selective absorption, to which the color of a mineral is due, more especially by transmitted light, varies according to the molecular structure of the crystals. It is hence one of the special optical characters depending upon the crystallization, which are discussed later. Here belong *dichroism* or *pleochroism*, the property of exhibiting different colors in different directions by transmitted light. This subject is explained further in Arts. 365 and 393.

336. Varieties of Color.—The following eight colors were selected by Werner as fundamental, to facilitate the employment of this character in the description of minerals: *white, gray, black, blue, green, yellow, red, and brown*.

(a) The varieties of METALLIC COLORS recognized are as follows:

1. *Copper-red*: native copper.—2. *Bronze-yellow*: pyrrhotite.—3. *Brass-yellow*: chalcopryrite.—4. *Gold-yellow*: native gold.—5. *Silver-white*: native silver, less distinct in arsenopyrite.—6. *Tin-white*: mercury; cobaltite.—7. *Lead-gray*: galena, molybdenite.—8. *Steel-gray*: nearly the color of fine-grained steel on a recent fracture; native platinum, and palladium.

(b) The following are the varieties of NON-METALLIC COLORS:

A. WHITE. 1. *Snow-white*: Carrara marble.—2. *Reddish white*, 3. *Yellowish white* and 4. *Grayish white*: all illustrated by some varieties of calcite and quartz.—5. *Greenish white*: talc.—6. *Milk-white*: white, slightly bluish; some chalcedony.

B. GRAY. 1. *Bluish gray*: gray, inclining to dirty blue.—2. *Pearl-gray*: gray, mixed with red and blue; cerargyrite.—3. *Smoke-gray*: gray, with some brown; flint.—4. *Greenish gray*: gray, with some green; cat's-eye; some varieties of talc.—5. *Yellowish gray*: some varieties of compact limestone.—6. *Ash-gray*: the purest gray color; zoisite.

C. BLACK. 1. *Grayish black*: black, mixed with gray (without green, brown, or blue tints); basalt; Lydian stone.—2. *Velvet-black*: pure black; obsidian, black tourmaline.—3. *Greenish black*: augite.—4. *Brownish black*: brown coal, lignite.—5. *Bluish black*: black cobalt.

D. BLUE. 1. *Blackish blue*: dark varieties of azurite.—2. *Azure-blue*: a clear shade of bright blue; pale varieties of azurite, bright varieties of lazulite.—3. *Violet-blue*: blue, mixed with red; amethyst, fluorite.—4. *Lavender-blue*: blue, with some red and much gray.—5. *Prussian-blue*, or Berlin blue: pure blue; sapphire, cyanite.—6. *Small-blue*: some varieties of gypsum.—7. *Indigo-blue*: blue, with black and green; blue tourmaline.—8. *Sky-blue*: pale blue, with a little green; it is called mountain-blue by painters.

E. GREEN. 1. *Verdigris-green*: green, inclining to blue; some feldspar (amazon-stone).—2. *Celandine-green*: green, with blue and gray; some varieties of talc and beryl. It is the color of the leaves of the celandine (*Chelidonium majus*).—3. *Mountain-green*: green, with

much blue; beryl.—4. *Leek-green*: green, with some brown; the color of leaves of garlic; distinctly seen in prase, a variety of quartz.—5. *Emerald-green*: pure deep green; emerald.—6. *Apple-green*: light green with some yellow; chrysoprase.—7. *Grass-green*: bright green, with more yellow; green diallage.—8. *Pistachio-green*: yellowish green, with some brown; epidote.—9. *Asparagus-green*: pale green, with much yellow; asparagus stone (apatite).—10. *Blackish green*: serpentine.—11. *Olive-green*: dark green, with much brown and yellow; chrysolite.—12. *Oil-green*: the color of olive-oil; beryl, pitchstone.—13. *Siskin-green*: light green, much inclining to yellow; uranite.

F. YELLOW. 1. *Sulphur-yellow*: sulphur.—2. *Straw-yellow*: pale yellow; topaz.—3. *Wax-yellow*: grayish yellow with some brown; blende, opal.—4. *Honey-yellow*: yellow, with some red and brown; calcite.—5. *Lemon-yellow*: sulphur, orpiment.—6. *Ocher-yellow*: yellow, with brown; yellow ocher.—7. *Wine-yellow*: topaz and fluorite.—8. *Cream-yellow*: some varieties of lithomarge.—9. *Orange-yellow*: orpiment.

G. RED. 1. *Aurora-red*: red, with much yellow; some realgar.—2. *Hyacinth-red*: red, with yellow and some brown; hyacinth garnet.—3. *Brick-red*: polyhalite, some jasper.—4. *Scarlet-red*: bright red, with a tinge of yellow; cinnabar.—5. *Blood-red*: dark red, with some yellow; pyrope.—6. *Flesh-red*: feldspar.—7. *Carmine-red*: pure red; ruby sapphire.—8. *Rose-red*: rose quartz.—9. *Crimson-red*: ruby.—10. *Peachblossom-red*: red, with white and gray; lepidolite.—11. *Columbine-red*: deep red, with some blue; garnet.—12. *Cherry-red*: dark red, with some blue and brown; spinel, some jasper.—13. *Brownish-red*: jasper, limonite.

H. BROWN. 1. *Reddish brown*: garnet, zircon.—2. *Clove-brown*: brown, with red and some blue; axinite.—3. *Hair-brown*: wood opal.—4. *Broccoli-brown*: brown, with blue, red, and gray; zircon.—5. *Chestnut-brown*: pure brown.—6. *Yellowish brown*: jasper.—7. *Pinchbeck-brown*: yellowish-brown, with a metallic or metallic-pearly luster; several varieties of talc, bronzite.—8. *Wood-brown*: color of old wood nearly rotten; some specimens of asbestos.—9. *Liver-brown*: brown, with some gray and green; jasper.—10. *Blackish brown*: bituminous coal, brown coal.

3. LUSTER.

337. Nature of Luster.—The luster of minerals varies with the nature of their surfaces. A variation in the quantity of light reflected produces different degrees of intensity of luster; a variation in the nature of the reflecting surface produces different kinds of luster.

338. Kinds of Luster.—The kinds of luster recognized are as follows:

1. METALLIC: the luster of the metals, as of gold, copper, iron, tin.

In general, a mineral is not said to have metallic luster unless it is opaque in the mineralogical sense, that is, it transmits no light on the edges of thin splinters. Some minerals have varieties with metallic and others with unmetallic luster; this is true of hematite.

Imperfect metallic luster is expressed by the term *sub-metallic*, as illustrated by columbite, wolframite. Other kinds of luster are described briefly as UNMETALLIC.

2. *Adamantine*: the luster of the diamond. When also sub-metallic, it is termed *metallic-adamantine*, as cerussite, pyrargyrite.

Adamantine luster belongs to substances of high refractive index. This may be connected with their relatively great density (and hardness), as with the diamond, also corundum, etc.; or because they contain heavy molecules, thus most compounds of lead, not metallic in luster, have a high refractive index and an adamantine luster.

3. *Vitreous*: the luster of broken glass. An imperfectly vitreous luster is termed *sub-vitreous*. The vitreous and sub-vitreous lusters are the most common in the mineral kingdom. Quartz possesses the former in an eminent degree; calcite, often the latter.

4. *Resinous*: luster of the yellow resins, as opal, and some yellow varieties of sphalerite.

5. *Greasy*: luster of oily glass. This is near resinous luster, but is often quite distinct, as elæolite.

6. *Pearly*: like pearl, as talc, brucite, stilbite, etc. When united with sub-metallic, as in hypersthene, the term *metallic-pearly* is used.

Pearly luster belongs to the light reflected from a pile of thin glass-plates; similarly it is exhibited by minerals, which, having a perfect cleavage, may be partially separated into successive plates, as on the basal plane of apophyllite. It is also shown for a like reason by foliated minerals, as talc and brucite.

7. *Silky*: like silk; it is the result of a fibrous structure. Ex. fibrous calcite, fibrous gypsum.

The different degrees and kinds of luster are often exhibited differently by unlike faces of the same crystal, but always similarly by like faces. The lateral faces of a right square prism may thus differ from a terminal, and in the right rectangular prism the lateral faces also may differ from one another. For example, the basal plane of apophyllite has a pearly luster wanting in the prismatic faces, they having a vitreous luster.

As shown by Haidinger, only vitreous, adamantine, and metallic luster belong to faces perfectly smooth and pure. In the first, the refractive index of the mineral is 1.3-1.8; in the second, 1.9-2.5; in the third, about 2.5. The true difference between metallic and vitreous luster is due to the effect which the different surfaces have upon the reflected light; in general, the luster is produced by the union of two simultaneous impressions made upon the eye. If the light reflected from a metallic surface be examined by a nicol prism (or the dichroscope of Haidinger, Art. 365), it will be found that both rays, that vibrating in the plane of incidence and that whose vibrations are normal to it, are alike, each having the color of the material, only differing a little in brilliancy; on the contrary, of the light reflected by a vitreous substance, those rays whose vibrations are at right angles to the plane of incidence are more or less polarized, and are colorless, while those whose vibrations are in this plane, having penetrated somewhat into the medium and suffered some absorption, show the color of the substance itself. A plate of red glass thus examined will show a colorless and a red image. Adamantine luster occupies a position between the others.

339. Degrees of Luster.—The *degrees of intensity* of luster are denominated as follows:

1. *Splendent*: reflecting with brilliancy and giving well-defined images, as hematite, cassiterite.

2. *Shining*: producing an image by reflection, but not one well-defined, as celestite.

3. *Glistening*: affording a general reflection from the surface, but no image, as talc, chalcopryrite.

4. *Glimmering*: affording imperfect reflection, and apparently from points over the surface, as flint, chalcedony.

A mineral is said to be *dull* when there is a total absence of luster, as chalk, the ochers, kaolin.

340. Play of Colors. Opalescence. Iridescence.—The term *play of colors* is used to describe the appearance of several prismatic colors in rapid succession on turning the mineral. This property belongs in perfection to the diamond, in which it is due to its high dispersive power. It is also observed in precious opal, where it is explained on the principle of interference; in this case it is most brilliant by candle-light.

The expression *change of colors* is used when each particular color appears to pervade a larger space than in the play of colors and the succession produced by turning the mineral is less rapid. This is shown in labradorite, as explained under that species.

Opalescence is a milky or pearly reflection from the interior of a specimen. Observed in some opal, and in cat's-eye.

Iridescence means the exhibition of prismatic colors in the interior or on the surface of a mineral. The phenomena of the play of colors, iridescence, etc., are sometimes to be explained by the presence of minute foreign crystals, in parallel positions; more generally, however, they are caused by the presence of fine cleavage-lamellæ, in the light reflected from which interference takes place, analogous to the well-known Newton's rings (see Art. 313).

341. Tarnish—A metallic surface is tarnished when its color differs from that obtained by fracture, as is the case with specimens of bornite. A surface possesses the *steel tarnish* when it presents the superficial blue color of tempered steel, as columbite. The tarnish is *irised* when it exhibits fixed prismatic colors, as is common with the hematite of Elba. These tarnish and iris colors of minerals are owing to a thin surface or film, proceeding from different sources, either from a change in the surface of the mineral or from foreign incrustation; hydrated iron oxide, usually formed from pyrite, is one of the most common sources of it, and produces the colors on anthracite and hematite.

342. Asterism.—This name is given to the peculiar star-like rays of light observed in certain directions in some minerals. This is seen by reflected light in the form of a six-rayed star in sapphire, and is also well shown by transmitted light (as of a small flame) with the phlogopite mica from South Burgess, Canada. In the former case it is explained by the presence of thin twinning-lamellæ symmetrically arranged. In the other case it is due to the presence of minute inclosed crystals, also symmetrically arranged, which are probably rutile or tourmaline in most cases. Crystalline faces which have been artificially etched also sometimes exhibit asterism. The peculiar light-figures sometimes observed in reflected light on the faces of crystals, either natural or etched, are of similar nature.

343. Schillerization.—The general term *schiller* (from the German) is applied to the peculiar luster, sometimes nearly metallic, observed in definite directions in certain minerals, as conspicuously in schiller-spar (an altered variety of bronzite), also in diallage, hypersthene, sunstone, and others. It is explained by the reflection either from minute inclosed plates in parallel position or from the surfaces of minute cavities (negative crystals) having a common orientation. In many cases it is due to alteration which has developed these bodies (or the cavities) in the direction of solution-planes (see Art. 264). The process by which it has been produced is then called *schillerization*.

344. Fluorescence.—The emission of light from within a substance while it is being exposed to direct radiation, or in certain cases to an electrical discharge in a vacuum tube, is called *fluorescence*. It is best exhibited by fluorite, from which the phenomenon gained its name. Thus, if a beam of white light be passed through a cube of colorless fluorite a delicate violet color is called out in its path. This effect is chiefly due to the action of the ultra-violet rays, and is connected with a change of refrangibility in the transmitted light.

The electrical discharge from the negative pole of a vacuum tube calls out a brilliant fluorescence not only with the diamond, the ruby, and many gems, but also with calcite and other minerals. Such substances may continue to emit light, or *phosphoresce*, after the discharge ceases.

345. Phosphorescence.—The *continued* emission of light by a substance (not incandescent) produced especially after heating, exposure to light or to an electrical discharge, is called *phosphorescence*.

Fluorite becomes highly phosphorescent after being heated to about 150° C. Different varieties give off light of different colors; the *chlorophane* variety, an emerald-green light; others purple, blue, and reddish tints. This phosphorescence may be observed in a dark place by subjecting the pulverized mineral to a heat below redness. It is even called out by a sharp blow with a hammer. Some varieties of white limestone or marble, after slight heating, emit a yellow light; so also tremolite, danburite, and other species.

By the application of heat minerals lose their phosphorescent properties. But on passing electricity through the calcined mineral a more or less vivid light is produced at the time of the discharge, and subsequently the specimen when heated will often emit light as before. The light is usually of the same color as previous to calcination, but occasionally is quite different. It is in general less intense than that of the unaltered mineral, but is much increased by a repetition of the electric discharges, and in some varieties of fluorite it may be nearly or quite restored to its former brilliancy. It has also been found that some varieties of fluorite, and some specimens of diamond, calcite, and apatite, which are not naturally phosphorescent, may be rendered so by means of electricity. Electricity will also increase the natural intensity of the phosphorescent light.

Exposure to the light of the sun produces very apparent phosphorescence with many diamonds, but some specimens seem to be destitute of this power. This property is most striking after exposure to the blue rays of the spectrum, while in the red rays it is rapidly lost.

LITERATURE.

Asterism.

- Rose. Mica. Ber. Ak. Berlin, 614, 1862; 344, 1869.
Fr. von Kobell. Ber. Ak. München, 65, 1863.
Baumhauer. Calcite. Pogg. Ann., 138, 563, 1869; 139, 34; 140, 271, 1870.
Tschermak. Phlogopite. Zs. Kr., 2, 36, 1877.
Lacroix. Phlogopite. Bull. Soc. Min., 8, 99, 1885; 12, 314, 1889.

Schiller.

- Scheerer. Sunstone. Pogg. Ann., 64, 153, 1845.
Haidinger. Pogg. Ann., 70, 574; 71, 321, 1847; 76, 99, 1849.
Reusch. Pogg. Ann., 116, 392, 1862; 118, 256, 1863; 120, 95, 1863.
See also papers on labradorite by Reusch, Schrauf, Vogelsang; on hypersthene, by Kosmann, referred to on p. 142; further papers by Judd (p. 155).

Fluorescence, Phosphorescence.

- Becquerel. Ann. Ch. Phys., 55, 5-119, 1859.
H. Rose. Pogg. Ann., 35, 481, 1835.
Stokes. Phil. Trans., 142, 463, 1852; 143, 385, 1853. (Also in Pogg. Ann., 96, 523, 1855; Erg.-Bd., 4, 188, 1854.)
Also many other memoirs.