

V. CHARACTERS DEPENDING UPON ELECTRICITY AND MAGNETISM.

1. ELECTRICITY.

418. Electrical Conductivity.—The subject of the relative conducting power of different minerals is one of minor interest.* In general most minerals, except those having a metallic luster among the sulphides and oxides, are non-conductors. Only the non-conductors can show pyro-electrical phenomena, and only the conductors can give a thermo-electric current.

419. Frictional Electricity.—The development of an electrical charge on many bodies *by friction* is a familiar subject. All minerals become electric by friction, although the degree to which this is manifested differs widely. There is no line of distinction among minerals, dividing them into *positively* electric and *negatively* electric; for both electrical states may be presented by different varieties of the same species, and by the same variety in different states. The gems are in general positively electric only when polished; the diamond, however, exhibits positive electricity whether polished or not. It is a familiar fact that the electrification of amber upon friction was early observed (600 B. C.), and indeed the Greek name (*ἤλεκτρον*) later gave rise to the word electricity.

420. Pyro-electricity.—The simultaneous development of plus and minus charges of electricity on different parts of the same crystal when its temperature is suitably changed is called pyro-electricity. Crystals exhibiting such phenomena are said to be *pyro-electric*. This phenomenon was first observed in the case of tourmaline, which is rhombohedral-hemimorphic in crystallization, and it is particularly marked with crystals belonging to groups of relatively low symmetry, especially those of the hemimorphic type. It is possible, of course, only with non-conductors. This subject was early investigated by Riess and Rose (1843), later by Hankel, also by C. Friedel, Kundt, and others (see literature).

In all cases it is true that directions of like crystallographic symmetry show charges of like sign, while unlike directions may exhibit opposite charges. Substances not crystallized cannot show pyro-electricity. A few of the many possible examples will serve to bring out the most essential points.

Boracite (isometric-tetrahedral, p. 46) on heating exhibits + electricity on one set of tetrahedral faces and - electricity on the other. Cf. Fig. 567.

Tourmaline (rhombohedral-hemimorphic, p. 79) shows opposite charges at the opposite extremities of the vertical axis corresponding to its hemimorphic crystallization. In this and in other similar cases, the extremity which becomes positive on heating has been called the *analogous* pole, and that which becomes negative has been called the *antilogous* pole.

Calamine and *struvite* (orthorhombic-hemimorphic, p. 95) exhibit phenomena analogous to these of tourmaline.

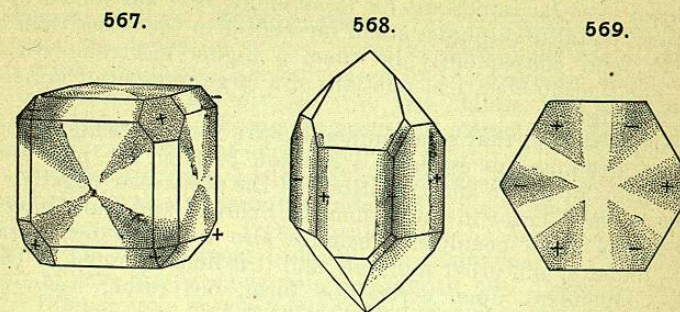
Quartz (rhombohedral-trapezohedral, p. 82) shows + electricity on heating at the three alternate prismatic edges and - electricity at the three remaining edges; the distribution for right-handed crystals is opposite to that of left-handed. Twins may exhibit a high degree of complexity. Cf. Figs. 568, 569.

Axinite (triclinic, p. 107), when heated to 120° or 130°, has an analogous pole (Riess & Rose) at the solid angle rxM' ; the antilogous pole at the angle $mr'M'$ near plane n .

A very convenient and simple method for investigating the phenomena is

* On the conductivity of minerals, see Beijerinck, *Jb. Min., Beil.-Bd. 11, 403, 1898.*

the following, which is due to Kundt: First heat the crystal or section carefully in an air-bath; pass it several times through the flame of an alcohol lamp and then place it on a little upright cylinder of brass to cool. While cooling, a mixture of red lead and sulphur finely pulverized and previously agitated is dusted over it through a fine cloth from a suitable bellows. The



positively electrified red lead collects on the parts having a negative charge, and the negatively electrified sulphur on those with a positive charge. This is illustrated by Figs. 567-569, and still better by the illustrations given by Kundt and others. (Cf. Plate III of Groth, *Phys. Kryst.*, 1895.)

421. Piezo-electricity.—The name *piezo-electricity* has been given to the development of electrical charges on a crystallized body by pressure. This is shown by a cleavage-mass of calcite, also by topaz. This phenomenon is most interesting where a relation can be established between the electrical excitement and the molecular structure, as is conspicuously true with quartz, tourmaline, and some other species.

This subject has been investigated by Hankel, Curie, and others, and discussed theoretically by Lord Kelvin (see literature). Hankel has also employed the term *actino-electricity*, or, better, *photo-electricity*, for the phenomenon of calling out of an electrical condition by the influence of direct radiation; fluorite is a conspicuous example.

422. Röntgen-rays in Mineralogy.—The power of different minerals to transmit the so-called X-rays, or Röntgen-rays, emitted from a suitable vacuum-tube during the discharge of an induction-coil has been investigated by Doelter.* He has found, for example, that sulphur, beryl, epidote, pyrite, etc., are nearly opaque; tourmaline less so; fluorite transmits the rays slightly, the feldspars and quartz better; corundum is nearly transparent and diamond and graphite are highly so. Diamond is easily distinguished in this way from its imitations, which are relatively highly opaque.

423. Thermo-electricity.—The contact of two unlike metals in general results in electrifying one of them positively and the other negatively. If, further, the point of contact be heated while the other parts, connected with a wire, are kept cool, a continuous current of electricity—shown, for example, by a suitable galvanometer—is set up at the expense of the heat-energy supplied. If, on the other hand, the point of junction is cooled, a current is set up in the reverse direction. This phenomenon is called *thermo-electricity*, and two metals so connected constitute a thermo-electric couple. Further it is found that different conductors can be arranged in order in a table—a so-

* *Jb. Min.*, 2, 87, 1896; 1, 256, 1897. Also Goodwin, *Nature*, April 30, 1896.

called thermo-electric series—according to the *direction* of the current set up on heating and according to the *electromotive force* of this current. Among the metals, bismuth (+) and antimony (−) stand at the opposite ends of the series; the current passes through the connecting wire from antimony to bismuth.

This subject is so far important for mineralogy, as it was shown by Bunsen that the natural metallic sulphides stand farther off in the series than bismuth and antimony, and consequently by them a higher electromotive force is produced. The thermo-electrical relations of a large number of minerals were determined by Flight.

It was early observed that some minerals have varieties which are both + and −. Rose attempted to establish a relation between the plus and minus pyritohedral forms of pyrite and cobaltite, and the positive or negative thermo-electrical character. Later investigations by Schrauf and Dana have shown, however, that the same peculiarity belongs also to glaucodot, tetradymite, skutterudite, danaitite, and other minerals, and it is demonstrated by them that it cannot be dependent upon crystalline form, but rather upon chemical composition.

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2. MAGNETISM.

424. Magnetic Minerals. Natural Magnets.—A few minerals in their natural state are capable of being attracted by a strong steel magnet; they are said to be *magnetic*. This is conspicuously true of magnetite, the magnetic oxide of iron; also of pyrrhotite or magnetic pyrites, and of some varieties of native platinum (especially the variety called iron-platinum).

A number of other minerals, as hematite, franklinite, etc., are in some cases attracted by a steel magnet, but probably in most if not all cases because

* See Liebig, Phys. Krystallographie, 1891, for a full discussion of the topics briefly touched upon in the preceding pages, also for references to original articles.

of admixed magnetite (but see Art. 426). Occasional varieties of the three minerals mentioned above, as the lodestone variety of magnetite, exhibit themselves the attracting power and polarity of a true magnet. They are then called *natural magnets*. In such cases the magnetic polarity has probably been derived from the inductive action of the earth, which is itself a huge magnet.

425. Paramagnetism. Diamagnetism.—In a very strong magnetic field, as that between the poles of a very powerful electromagnet, all minerals, as indeed all other substances, are influenced by the magnetic force. According to their behavior they are divided into two classes, the *paramagnetic* and *diamagnetic*; those of the former appear to be attracted, those of the latter to be repelled. For purposes of experiment the substance in question, in the form of a rod, is suspended on a horizontal axis between the poles of the magnet. If paramagnetic, it takes a position parallel to the magnetic axis; if diamagnetic, it sets transversely to it. Iron, cobalt, nickel, manganese, platinum are paramagnetic; silver, copper, bismuth are diamagnetic. Among minerals compounds of iron are paramagnetic, as siderite, also diopside; further beryl, diopside. Diamagnetic species include calcite, zircon, wulfenite, etc.

By the use of a sphere it is possible to determine the relative amount of magnetic induction in different directions of the same substance. Experiment has shown that in isometric crystals the magnetic induction is alike in all directions; in those optically uniaxial, that there is a direction of maximum and, normal to it, one of minimum magnetic induction; in biaxial crystals, that there are three unequal magnetic axes, the position of which may be determined. In other words, the magnetic relations of the three classes of crystals are analogous to their optical relations.

426. Corresponding to the facts just stated, that all compounds of iron are paramagnetic, it is found that a sufficiently powerful electromagnet attracts all minerals containing iron, though except in the cases given in Art. 424 a bar magnet has no sensible influence upon them; hence the efficiency of the electromagnet method of separating ores.

Plücker* determined the magnetic attraction of a number of substances compared with iron taken as 100,000. For example, for magnetite he obtained 40,227; for hematite, crystallized, 533, massive, 134; limonite, 71; pyrite, 150.

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* Pogg. Ann., 74, 343, 1848.

VI. TASTE AND ODOR.

In their action upon the senses a few minerals possess *taste*, and others under some circumstances give off *odor*.

427. Taste belongs only to soluble minerals. The different kinds of taste adopted for reference are as follows:

1. *Astringent*: the taste of vitriol.
2. *Sweetish astringent*: taste of alum.
3. *Saline*: taste of common salt.
4. *Alkaline*: taste of soda.
5. *Cooling*: taste of saltpeter.
6. *Bitter*: taste of Epsom salts.
7. *Sour*: taste of sulphuric acid.

428. Odor.—Excepting a few gaseous and soluble species, minerals in the dry unchanged state do not give off odor. By friction, moistening with the breath, and the elimination of some volatile ingredient by heat or acids, odors are sometimes obtained which are thus designated:

1. *Alliaceous*: the odor of garlic. Friction of arsenical iron elicits this odor; it may also be obtained from arsenical compounds by means of heat.
2. *Horse-radish odor*: the odor of decaying horse-radish. This odor is strongly perceived when the ores of selenium are heated.
3. *Sulphurous*: friction elicits this odor from pyrite, and heat from many sulphides.
4. *Bituminous*: the odor of bitumen.
5. *Fetid*: the odor of sulphureted hydrogen or rotten eggs. It is elicited by friction from some varieties of quartz and limestone.
6. *Argillaceous*: the odor of moistened clay. It is obtained from serpentine and some allied minerals, after moistening them with the breath; others, as pyrrargillite, afford it when heated.

429. Feel.—The FEEL is a character which is occasionally of some importance; it is said to be *smooth* (sepiolite), *greasy* (talc), *harsh*, or *meager*, etc. Some minerals, in consequence of their hygroscopic character, *adhere to the tongue* when brought in contact with it.

PART III. CHEMICAL MINERALOGY.

GENERAL PRINCIPLES OF CHEMISTRY AS APPLIED TO MINERALS.

430. Minerals, as regards their chemical constitution, are either the uncombined elements in a native state, or definite compounds of these elements formed in accordance with chemical laws. It is the object of Chemical Mineralogy to determine the chemical composition of each species; to show the chemical relations of different species to each other where such exist; and also to explain the methods of distinguishing different minerals by chemical means. It thus embraces the most important part of Determinative Mineralogy.

In order to understand the chemical constitution of minerals, some knowledge of the fundamental principles of Chemical Philosophy is required; and these are here briefly recapitulated.

431. Chemical Elements.—Chemistry recognizes about seventy substances which cannot be decomposed, or divided into others, by any process of analysis at present known; these substances are called the chemical *elements*. A list of them is given in a later article (436); common examples are: Oxygen, nitrogen, hydrogen, chlorine, gold, silver, sodium, etc.

432. Atom. Molecule.—The study of the chemical properties of substances and of the laws governing their formation has led to the belief that there is for each element a definite, indivisible mass, which is the smallest particle which can play a part in chemical reactions; this indivisible unit is called the *atom*.

With some rare exceptions, the atom cannot exist alone, but unites by the action of what is called chemical force, or chemical affinity, with other atoms of the same or different kind to form the *molecule*. The molecule, in the chemical sense, may be defined as the smallest particle into which a given kind of substance can be subdivided without undergoing chemical decomposition. For example, two *atoms* of hydrogen unite to form a *molecule* of hydrogen gas. Again, one atom of hydrogen and one of chlorine form a molecule of hydrochloric acid gas; two atoms of hydrogen and one of sulphur form a molecule of the gas hydrogen sulphide.

433. Physical Molecules.—An important distinction must be made between the simple chemical molecules, regarded as made up of the smallest possible number of the atoms of each kind, united in the given proportion, and the actual *physical molecules* which together build up the structure of a particular