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V. CHARACTERS DEPENDING UPON ELECTRICITY AND MAGNETISM

1. ELECTRICITY

436. 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.

437. 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.

438. Pyro-electricity. — The simultaneous development of positive and negative 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. 66) on heating exhibits + electricity on one set of tetrahedral faces and - electricity on the other. Cf. Fig. 619.

Tourmaline (rhombohedral-hemimorphic, p. 109) 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

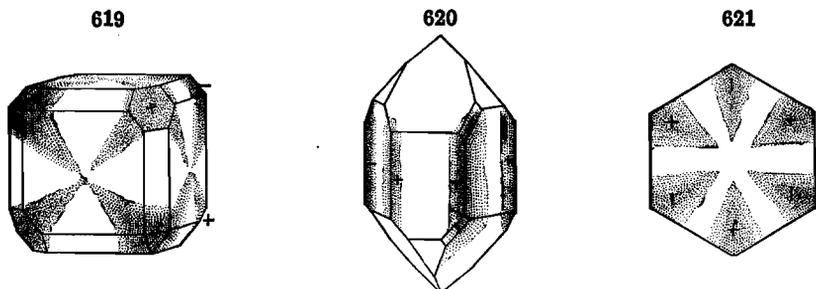
* On the conductivity of minerals, see Beijerinck, Jb. Min., Beil.-Bd., **11**, 403, 1898.

becomes positive on heating has been called the *analogous* pole, and that which becomes negative has been called the *antilogous* pole.

Calamine and *struwite* (orthorhombic-hemimorphic, p. 126) exhibit phenomena analogous to those of tourmaline.

Quartz (rhombohedral-trapezohedral, p. 112) 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. 620, 621.

Axinite (triclinic, p. 144), 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 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. 619-621, and still better by the illustrations given by Kundt and others. (Cf. Plate III of Groth, *Phys. Kryst.*, 1905.)

439. 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 producing an electrical condition by the influence of direct radiation; fluorite is a conspicuous example.

440. 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-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 positive and negative 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, danaites, 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

441. 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

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

cases attracted by a steel magnet, but probably in most if not all cases because of admixed magnetite (but see Art. 443). 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.

442. 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; that in those optically uniaxial, there is a direction of maximum and, normal to it, one of minimum magnetic induction; that in biaxial crystals, 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.

443. 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. 441, a bar magnet has no sensible influence upon them; hence the efficiency of the electromagnetic 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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