After all the various possible explanations have been applied there still remain, however, many species about which no certain conclusion can be reached. To many of these species the theory of Mallard may probably be applicable. Indeed it may be added that much difference of opinion still exists as to the cause of the "optical anomalies" in a considerable number of minerals.

LITERATURE

Optical Anomalies *

Brewster. Many papers in Phil. Trans., 1814, 1815, and later; also in Ed. Trans., Ed. Phil. J., etc.

Biot. Recherches sur la polarisation lamellaire, etc. C. R., **12**, 967, 1841; **13**, 155, 391, 839, 1841; in full in Mem. de l'Institut, **18**, 539.

Volger. Monographie des Boracits. Hannover, 1857.

Marbach. Ueber die optischen Eigenschaften einiger Krystalle des tesseralen Systems. Pogg. Ann., **94**, 412, 1855.

Pfaff. Versuche über den Einfluss des Drucks auf die optischen Eigenschaften der Krystalle. Pogg. Ann., **107**, 333, 1859; **108**, 598, 1859.

Des Cloizeaux. Ann. Mines **11**, 261, 1857; **14**, 339, 1858, **6**, 557, 1864. Also Nouvelles Recherches, etc., 1867.

Reusch. Ueber die sogenannte Lamellarpolarisation des Alauns. Pogg. Ann., **132**, 618, 1867.

Rumpf. Apophyllite. Min. petr. Mitth., **2**, 369, 1870.

Hirschwald. Leucite. Min. Mitth., 227, 1875.

Lasaulx. Tridymite. Zs. Kr., **2**, 253, 1878.

Mallard. Application des phénomènes optiques anomaux que présentent un grand nombre de substances cristallisées. Annales des Mines (Ann. Min.) **10**, pp. 60–196, 1876 (Abstract in Zs. Kr., **1**, 309–320). See also Bull. Soc. Min., **1**, 107, 1878. Sur les propriétés optiques des mélanges de substances isomorphes et sur les anomalies optiques des cristaux. Bull. Soc. Min., **3**, 3, 1880. Also ibid., **4**, 71, 1881; **5**, 144, 1882.

Bertrand. Numerous papers in Bull. Soc. Min., 1878–1882.

Becke. Chabazite. Min. petr. Mitth., **2**, 391, 1879.

Baumhauer. Perovskite. Zs. Kr., **4**, 187, 1879.

Tschermak. " Mimetische Formen." Zs. G. Ges., **31**, 637, 1879.

Jannettaz. Diamond. Bull. Soc. Min., **2**, 124, 1879; alum, ibid., **2**, 191; **3**, 20.

Bücking. Ueber durch Druck hervorgerufene optische Anomalien. Zs. G. Ges., **32**, 199, 1880. Also, Zs. Kr., **7**, 555, 1883.

Arzruni and **S. Kock.** Analcite. Zs. Kr., **5**, 483, 1881.

Klocke. Ueber Doppelbrechung regulärer Krystalle. Jb. Min., **1**, 53, 1880 (also **2**, 97, 13 ref.; **1**, 204, 1881, and Verh. nat. Ges. Freiburg, **8**, 31). Ueber einige optische Eigenschaften optisch anomaler Krystalle und deren Nachahmung durch gespannte und gepresste Colloide. Jb. Min., **2**, 249, 1881.

C. Klein. Boracite. Jb. Min., **2**, 209, 1880; **1**, 239, 1881; **1**, 235, 1884. Garnet. Nachr. Ges. Göttingen, 1882; Jb. Min., **1**, 87, 1883. Apophyllite (influence of heat). Jb. Min., **2**, 165, 1892. Garnet, vesuvianite, etc. Ibid., **2**, 68, 1895.

W. Klein. Beiträge zur Kenntniss der optischen Aenderungen in Krystallen unter dem Einflusse der Erwärmung. Zs. Kr., **9**, 38, 1884.

Brauns. Die optischen Anomalien der Krystalle. (Preisschrift), Leipzig, 1891. Also earlier papers: Jb. Min., **2**, 102, 1883; **1**, 96, 1885; **1**, 47, 1887.

Ben Saude. Beitrag zu einer Theorie der Optischen Anomalien der regulären Krystalle. Lisbon, 1894. Also earlier: Analcite, Jb. Min., **1**, 41, 1882. Perovskite (Preisschrift), Göttingen, 1882.

Wallerant. Théorie des anomales optiques, de l'isomorphisme et du polymorphisme. Bull. Soc. Min., **21**, 188, 1898.

IV. CHARACTERS DEPENDING UPON HEAT

430. The more important of the special properties of a mineral species with respect to heat include the following: Fusibility; conductivity and expansion,

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* A complete bibliography is given in the memoir by Brauns (1891), see above.

especially in their relation to crystalline structure; change in optical characters with change of temperature; specific heat; also diathermancy, or the power of transmitting heat radiation. The full discussion of these and other related subjects lies outside of the range of the present text-book. A few brief remarks are made upon them, and beyond these reference must be made to text-books on Physics and to special memoirs, some of which are mentioned in the literature (p. 305).

431. Fusibility. — The approximate relative fusibility of different minerals is an important character in distinguishing different species from one another by means of the blowpipe. For this purpose a scale is conveniently used for comparison, as explained in the articles later devoted to the blowpipe. Accurate determinations of the fusibility are difficult, and though of little importance for the above object, they are interesting from a theoretical standpoint. They have been attempted by various authors by the use of a number of different methods. The following are the approximate melting-point values for the minerals used in von Kobell's scale (Art. **491**): Stibnite, 525°; natrolite, 965°; almandite, 1200°; actinolite, 1296°; orthoclase, 1200°; bronzite, 1380°; also for quartz, about 1600°.

432. Conductivity. — The conducting power of different crystallized media was early investigated by Sénarmont. He covered the faces of the substance under investigation with wax and observed the form of the figure melted by a hot wire placed in contact with the surface at its middle point. Later investigations have been made by Röntgen (who modified the method of Sénarmont), by Jannettaz, and others. In general it is found that, as regards their thermal conductivity, crystals are to be divided into the three classes noted on p. 252. In other words, the conductivity for heat seems to follow the same general laws as the propagation of light. It is to be stated, however, that experiments by S. P. Thompson and O. J. Lodge have shown a different rate of conductivity in tourmaline in the opposite directions of the vertical axis.

433. Expansion. — Expansion, that is, increase in volume upon rise of temperature, is a nearly universal property for all solids. The increment of volume for the unit volume in passing from 0° to 1° C. is called the coefficient of expansion. This quantity has been determined for a number of species. Further, the relative expansion in different directions is found to obey the same laws as the light-propagation. Crystals, as regards heat-expansion, are thus divided into the same three classes mentioned on p. 252 and referred to in the preceding article.

The amount of expansion varies widely, and, as shown by Jannettaz, is influenced particularly by the cleavage. Mitscherlich found that in calcite there was a diminution of 8′ 37″ in the angle of the rhombohedron on passing from 0° to 100° C., the form thus approaching that of a cube as the temperature increased. The rhombohedron of dolomite, for the same range of temperature, diminishes 4′ 46″; and in aragonite, for a rise in temperature from 21° to 100°, the angle of the prism diminishes 2′ 46″. In some rhombohedrons, as of calcite, the vertical axis is lengthened (and the horizontal shortened), while in others, like quartz, the reverse is true. The variation is such in both cases that the birefringence is diminished with the increase of temperature, for calcite possesses negative double refraction, and quartz, positive.

It is to be noted that in general the expansion by heat, while it may serve to alter the angles of crystals, other than those of the isometric system, does not alter the zone-relations and the crystalline symmetry. In certain cases, however, the effect of heat may be to give rise to twinning-lamellæ (as in anhydrite) or to cause their disappearance (as in calcite). Rarely heat serves to develop a new molecular structure; thus, as explained in Art. **429,** boracite and leucite, which are anisotropic at ordinary temperatures, become isotropic when heated, the former to 300° the latter to 500° or 600°. The change in the optical properties of crystals produced by heat has already been noticed (Art. **422**).

434. Specific Heat. — Determinations of the specific heat of many minerals have been made by Joly, by Oeberg, and others. Some of the results reached are as follows:

	Joly	Oeberg		Joly	Oeberg
Galena, *cryst.*	0·0541	—	Orthoclase	0·1869	0·1877
Chalcopyrite	0·1271	0·1291	Albite	0·1983	0·1976
Pyrite	0·1306	—	Amphibole, *black*	0·1963	Augite 0·1830
Hematite	0·1683	0·1645	Beryl	0·2066	0·1979
Garnet, *red cryst.*	0·1780 – 0·1793	0·1758	Calcite	0·2034 – 0·2044	0·2042
Epidote	0·1877	0·1861	Aragonite	0·2036	—

435. Diathermancy. — Besides the slow molecular propagation of heat in a body, measured by its thermal conductivity, there is also to be considered the rapid propagation of what is called radiant heat through it by the wave-motion of the ether which surrounds its molecules. This is merely a part of the general subject of light-propagation already fully discussed, since heat-waves, in the restricted sense, differ from light-waves only in their relatively greater length. The degree of absorption exerted by the body is measured by its diathermancy, which corresponds to transparency in light. In this sense halite, sylvite, and fluorite are highly *diathermanous,* since they absorb but little of the heat-waves passing through them; on the other hand, gypsum and, still more, alum are comparatively *athermanous,* since while transparent to the short light-waves they absorb the long heat-waves, transforming the energy into that of sensible heat. Measurements of the diathermancy were early made by Melloni, later by Tyndall, Langley, and others.

LITERATURE

Heat

Mitscherlich. Pogg. Ann., **1,** 125, 1824; **10,** 137, 1827.

F. E. Neumann. Gypsum. Pogg. Ann., **27,** 240, 1833.

Sénarmont. Ann. Ch. Phys., **21,** 457, 1847; **22,** 179, 1848; also in Pogg. Ann., **73,** 191; **74,** 190; **75,** 50, 482.

Ångström. Pogg. Ann., **86,** 206, 1852.

Grailich and von Lang. Ber. Ak. Wien, **33,** 369, 1858.

Fizeau. Thermal expansion. C. R., **58,** 923, 1864. Ann. Ch. Phys., **2,** 143, 1864; **8,** 335, 1866; also C. R., 1864–1867.

C. Neumann. Pogg. Ann., **114,** 492, 1868.

Pape. Thermic axes of blue vitriol. Wied. Ann., **1,** 126, 1877.

Röntgen. Pogg. Ann., **151,** 603, 1874; Zs. Kr., **3,** 17, 1878.

Jannettaz. Conductivity of crystals. Bull. Soc. Geol., (3) **1,** 117, 252; **2,** 264; **3,** 499; **4,** 116, 554; **9,** 196. Bull. Soc. Min., **1,** 19, 1879. C. R., 1848, **114,** 1352, 1892.

O. J. Lodge. Thermal conductivity. Phil. Mag., **5,** 110, 1878.

S. P. Thompson and O. J. Lodge. Conductivity of tourmaline. Phil. Mag., **8,** 18, 1879.

Arzruni. Effect of heat on refractive indices of barite, etc. Zs. Kr., **1,** 165, 1877.

Beckenkamp. Expansion of monoclinic and triclinic crystals. Zs. Kr., **5,** 436, 1881.

H. Dufet. Effect of heat on refractive indices of gypsum. Bull. Soc. Min., **4,** 113, 191, 1881.

A. Schrauf. Sulphur. Zs. Kr., **12,** 321, 1887; TiO_2, ibid., **9,** 433, 1884.
L. Fletcher. Expansion of crystals. Zs. Kr., **4,** 337, 1880.
Joly. Meldometer. Ch. News, **65,** 1, 16, 1892, and Proc. Roy. Irish Acad., **2,** 38, 1891. Specific heat. Proc. Roy. Soc., **41,** 250, 352, 1887.
Oeberg. Specific heat. Oefv. Ak. Stockh., No. 8, 43, 1885.
Doelter. For methods and results in fusing silicates, see Handbuch der Mineralchemie, **1,** 628 *et seq.*

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

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