Crystals of iron phosphide (Rhabdite) from a blast-furnace.

By L. J. Spencer, M.A., F.G.S.

Assistant in the Mineral Department of the British Museum.

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THE crystals here described were sent by Dr. J. E. Stead, F.R.S., for crystallographic determination. They came from a 'bear' or mass of metal weighing about 300 tons that had solidified at the bottom of one of the blast-furnaces of Messrs. Cochrane & Co., Ltd., at Ormesby, near Middlesborough. They are present only in sparing amount in drusy cavities, and are absent in the mass of metal itself. These drusy cavities are lined with 'fir-tree crystallites' of metallic iron, which consist of small peg-like crystals grouped in lines along three directions at right angles. Resting on these and often extending completely across the small spaces are the bright needles of iron phosphide. The amount of material was unfortunately insufficient for a chemical analysis, but the presence of phosphorus and iron was confirmed: nickel is absent.

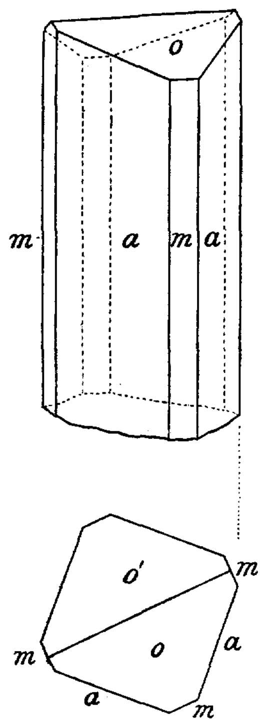
Iron phosphide is also present as a coating on the surface of the 'fir-tree crystallites', the core of which consists of metallic iron. The cavities also contain a few blade-like crystals of iron carbide; these are tin-white with brilliant metallic lustre, strongly magnetic, and very similar in general appearance to the needles of iron phosphide. Inferior measurements on the goniometer suggest that they are distorted cubic crystals flattened parallel to a face of the cube and with octahedral faces on the long edges of the blades.

The needles of iron phosphide are tin-white in colour with a brilliant metallic lustre, and sometimes a yellowish tarnish. They are brittle, and break with a sub-conchoidal cross-fracture. They are strongly magnetic, being readily attracted by a magnetic needle. In length they range from 1 to 3 mm. and in thickness 0·1–0·25 mm. They have the form of square prisms truncated on their edges by planes at 45°. The faces, however, often vary considerably in relative size: some are absent or visible only on the goniometer as a mere line, whilst others are largely developed, sometimes giving rise to a more or less pronounced platy habit of the crystals. The best goniometric readings in this prism-zone on several crystals were 44° 57′, 45° 0′, 45° 2′, 45° 4′, &c. The crystals are therefore presumably tetragonal.

Only three crystals with terminal faces were found, each of which shows only two pyramidal faces, as represented in the accompanying text-figure. This distribution of faces points to the symmetry being that of the scalenohedral or sphenoidal-hemihedral class of the tetragonal system, of which copper-pyrites is a well-known example. It is possible, however, that the class may be the sphenoidal-tetartohedral, but no doubly-terminated crystals have been observed. Etched figures would decide this point; but none could be produced. The best measurement obtained from a terminal face was the angle $mo = 63° 52'$, from which is calculated the axial ratio

$$a : c = 1 : 0{\cdot}3469.$$

On another crystal $mo = 63° 54'$. The readings oo' on the three crystals were 51° 51′, 52° 6′, and 52° 45′, mean 52° 14′; and the mean of all readings (mo and oo') gave $oo' = 52° 15'$. The only forms present on the crystals are $a\,\{100\}$, $m\,\{110\}$, and $o\,\{111\}$.



Crystal of Iron phosphide. (Sphenoidal-hemihedral tetragonal.)

Tetragonal crystals of iron phosphide have been previously measured and described by E. Mallard and by C. Hlawatsch. Crystals having the form of a right prism on a square base were prepared artificially by T. Sidot[1] in 1872; whilst still earlier, according to P. Daubrée,[2] prismatic crystals

[1] T. Sidot, 'Production d'un phosphure de fer cristallisé.' Compt. Rend. Acad. Sci. Paris, 1872, vol. lxxiv, p. 1425.

[2] P. Daubrée, 'Observations relatives au phosphure de fer cristallisé obtenu

of undetermined system had been made by Boblique. Mallard's[1] crystals had been formed by the burning of a coal seam at Commentry in France. They showed the same forms as the crystals now described, except that they were terminated by four pyramidal faces. Hlawatsch's[2] crystals were found in a mass of slag and iron in a blast-furnace at Beraun in Bohemia. These again showed the tetragonal forms *a* {100}, *m* {110}, and *o* {111}, but with only two, instead of four, pyramidal faces. Hlawatsch therefore suggested that the crystals belonged to the scalenohedral class.

The few angles that have been measured on the crystals from these three sources are tabulated below; they are in sufficiently close agreement to establish the identity of the materials.

Angle.	Mallard (1881).	Hlawatsch (1903).	Spencer.	
			Measured.	Calculated.
$oo' = 111:\bar{1}\bar{1}1$	—	*52° 10′	52° 14′	52° 16′
$oo = 111:\bar{1}11$	36° 18′	—	—	36 18
$mo = 110:111$	—	—	*63 52	—
$ao = 100:111$	*71 56	—	71 46	71 51
Axis *c*	0·3451	0·3462	—	0·3469

Although several phosphides of iron have been prepared in the laboratory, unfortunately the chemical composition of definitely crystallized material has not been satisfactorily determined. Sidot gave the composition as Fe_4P, whilst Mallard's material, analysed by A. Carnot, led to the formula Fe_7P_2. It is not, however, clear from the original descriptions whether these analyses were made on separated tetragonal crystals or on the associated crystalline mass. Dr. J. E. Stead[3] arrived

par M. Sidot.' Ibid., p. 1427. Boblique, Bull. Soc. Chim. Paris, 1866, vol. v, p. 248.

[1] E. Mallard, 'Sur la production d'un phosphure de fer cristallisé et du feldspath anorthite dans les incendies des houillères de Commentry.' Compt. Rend. Acad. Sci. Paris, 1881, vol. xcii, p. 933; Bull. Soc. Min. France, 1881, vol. iv, p. 230.

[2] C. Hlawatsch, 'Zwei krystallisierte Hüttenprodukte von Beraun.' Min. Petr. Mitt. (Tschermak), 1903, vol. xxii, p. 497.

[3] J. E. Stead, 'Iron and phosphorus.' Journ. Iron and Steel Inst., 1900, vol. lviii (No. ii for 1900), p. 79, plate IV, fig. 5. Similar outlines would be given by chance sections of the tetragonal crystals described above.

at the composition Fe_3P for crystallized material which showed rhomb-shaped outlines in section.

Iron phosphide has not been observed as a terrestrial mineral, but the frequent presence of iron-nickel phosphide, $(Fe,Ni)_3P$, containing about 15 to 30 per cent. of nickel replacing an equivalent amount of iron, has long been known in meteoric irons and stones, having been first detected by Berzelius in 1832. This was named schreibersite by W. Haidinger in 1847; and in 1864 G. Rose described acicular crystals, belonging to the tetragonal system, which he named rhabdite. Schreibersite and rhabdite have since been proved to be identical, although the latter name is still applied to crystals of the acicular habit as distinct from those of the platy habit. Figures of rhabdite crystals have been given by E. Cohen [1] and by E. Hussak,[2] but without satisfactory measurements capable of direct comparison with those given above. Nevertheless the identity of the artificial and meteoric crystals has been frequently assumed.

[1] E. Cohen and E. Weinschenk, 'Meteoreisen-Studien.' Ann. k. k. naturhist. Hofmuseums, Wien, 1891, vol. vi, p. 139. E. Cohen, 'Meteoreisen-Studien, III.' Ibid., 1894, vol. ix, p. 108. E. Cohen, 'Meteoritenkunde,' Stuttgart, 1894, pp. 125–128.

[2] E. Hussak in O. A. Derby, 'Estudo sobre o meteorito de Bendigó.' Archivos do Museu Nacional do Rio de Janeiro, 1896, vol. ix, p. 171.