On the Diathermancy of Antimonite.

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A DETERMINATION of the constants of elliptic polarization of light reflected from a fresh cleavage surface of antimonite enabled Professor P. Drude [1] to calculate two of the indices of refraction of this substance as 5·17 and 4·49 respectively. Instead, however, of the symmetry-axes of the crystal, regarded as belonging to the orthorhombic system, coinciding with the principal vibration directions in the plane (010), he found that the latter were inclined to the former lines at angles which varied in different observations between 2·6° and 15·4°. These observations, which indicate that the symmetry of antimonite is of the oblique or anorthic type [2], stand in opposition to those of Professor O. Mügge [3], who found that exceedingly thin flakes of antimonite placed between crossed nicols in direct sunlight transmitted sufficient light of a deep red colour to enable him to determine the extinction as straight.

As, however, the morphological and physical characters of antimonite taken as a whole, are those of an orthorhombic crystal, it seemed desirable to find, if possible, some new method of testing the transmission of radiant energy by crystalline substances, such as antimonite, which are opaque to light. A clue to such a method was found in an observation of Schultz-Sellack [4], who showed, some thirty years ago, that zinc-blende was very diathermanous, and that artificial sulphide of arsenic possessed the same property though to a less extent. It seemed probable therefore that antimonite might also be sufficiently diathermanous to enable its behaviour towards radiations of long wave-length to be determined, and to thus afford data on which conclusions as to its crystal-system might be based. On trial this proved to be the case, and the behaviour of a thin cleavage flake of antimonite was found to be consistent with orthorhombic symmetry [5].

[1] Ann. Phys. Chem. (Wiedemann), 1888, vol. xxxiv, p. 489.

[2] Loc. cit., p. 527.

[3] Neues Jahrb. Min., 1898, vol. i, p. 12.

[4] Ann. Phys. Chem. (Poggendorff), 1870, vol. cxxxix, p. 182.

[5] Since this paper was written E. C. Müller has published an elaborate investigation entitled 'Optische Studien am Antimonglanz,' Neues Jahrb. Min., 1903, Beil.-Bd.

Apparatus and mode of experimenting.—The source of radiation was an ordinary lime-light fed with coal-gas and oxygen. The radiation from the incandescent lime was focused on the thermo-couple of a Boys' radiomicrometer, placed at a distance of about 75 cm. from the lime, by means of a quartz lens 5 cm. in diameter and 9 cm. focal length. A microscope, provided with a rotating stage graduated in degrees, was fixed between the lens and the radiomicrometer. The tube of the microscope was placed horizontally and all the lenses removed. To adjust the flake of antimonite on the rotating stage, the flake was either placed between two pieces of cardboard in which holes had been made or else fastened by a little wax to a very thin piece of glass (a cover-slip). The latter proved to be the more convenient arrangement, as the amount of radiation stopped by the glass was found to be inappreciable. Before reaching the antimonite the heat-rays were polarized by passing through an ordinary nicol prism fitted in the substage of the microscope-stand. This prism was 5 cm. long and measured 2·5 cm. along the short diagonal of the end face. On the other side of the antimonite plate an analyser was fitted in the tube of the microscope: this was a square-ended prism measuring $4{\cdot}5 \times 1{\cdot}7 \times 1{\cdot}7$ cm.

The radiomicrometer, consisting of an antimony-bismuth couple suspended by a quartz fibre between the poles of a permanent magnet, was of the pattern described by Mr. Boys[1], and belongs to the Cavendish Laboratory. It is a very sensitive and trustworthy instrument, and I am greatly indebted to Professor J. J. Thomson for the loan of it[2]. The position of the image reflected from the mirror of the radiomicrometer was determined by means of a centimetre scale bent into a circular arc of 113 cm. radius, having for centre the position of the mirror. The readings were taken to 1 mm. and the maximum deviation observed, amounting to 18 cm., corresponds to a rotation of the radiomicrometer mirror through approximately 5°. Great care was taken to protect the radiomicrometer from stray radiations by means of suitable screens, and from vibration by mounting it on india-rubber blocks supported on a solid stone shelf built into the wall of the room in which the experiments were made, but in spite of these precautions the vibrations caused

xvii, pp. 187–251. This research, conducted by methods similar to those employed by Drude (loc. cit.), has led Müller to conclude that Drude was mistaken in attributing oblique or anorthic symmetry to antimonite, as all his own results are consistent with the view that antimonite crystallizes in the orthorhombic system.

[1] Phil. Trans. Roy. Soc., 1889, vol. clxxx, p. 159.

[2] I desire here to record my thanks to my friend Mr. Skinner, of the Cavendish Laboratory, for much kind help in setting up apparatus.

by traffic in the neighbouring street were a source of much inconvenience.

The arrangements, then, were essentially the same as those employed for examining crystal sections in parallel plane polarized light, the thermo-couple of the radiomicrometer being substituted for the observer's eye. It was found on trial that when the nicols were crossed no measurable radiation reached the radiomicrometer: on the other hand, when their principal planes were parallel the effect produced was so great that the spot of light instantly travelled off the scale.

A thin cleavage flake was next prepared from a crystal of Japanese antimonite. It proved on measurement to be 0·29 mm. thick. In some experiments the whole area of the plate (35 to 40 sq. mm.) was employed, in others it was limited to 20 sq. mm. by holes cut in the cardboard mount. The direction of the symmetry-axes lying in the cleavage face (010) can be easily identified either by the bounding edges made by planes belonging to the zone [100,010], or by the striae due to the presence of slip-planes lying in the zone [010,001]. By means of these striae the plate was brought into a definite position in the following way:—the tube of the microscope was fitted with a low power objective and with an eyepiece provided with cross-wires. The nicols were crossed and a quartz crystal adjusted on the stage so as to be in the position of extinction when the circle reading was 0°. The cross-wires were placed respectively parallel and perpendicular to the axis of the quartz crystal, which was then removed and replaced by the antimonite; this was in its turn adjusted till one of the cross-wires coincided with the striae. The eyepiece and objective were then removed, leaving the nicols untouched.

Now, since the striae on (010) are parallel to the brachy-axis of the crystal, and since these striae have been set to coincide with one or other of the vibration directions of the nicols, it follows that if the crystal is really orthorhombic the flake is in the position of extinction, and that on allowing the radiation to fall on it no indication should be given by the radiomicrometer, while on turning the flake in its own plane heat should be transmitted, the amount reaching a maximum for rotations of 45° from the zero position. On trial these predictions were found to be completely verified and the orthorhombic symmetry of antimonite confirmed.

Results.—The results obtained may be illustrated by the following figures:—

Circle:	0°	10°	20°	30°	40°	45°	50°	60°	70°	80°	90°.
Scale:	0	2	$7\frac{1}{2}$	$13\frac{1}{2}$	$17\frac{1}{2}$	18	$17\frac{1}{2}$	13	$6\frac{1}{2}$	$1\frac{1}{2}$	0.

Under the heading 'circle' are given the readings of the graduated stage to which the antimonite was attached; the readings being 0° or 90° when the vibration directions in the plate, as determined by the striae, coincided with the vibration directions of the nicols. Under 'scale' are given the corresponding deflections in cm. of the spot of light on the scale of the radiomicrometer, and these may be taken as directly proportional to the amount of heat transmitted.

These observations, while supporting those of Professor Mügge, stand in opposition to those of Professor Drude, as the results obtained by the latter require that the plate should transmit radiation when set in the position above described, but should cease to do so after being turned through an angle varying from 2° to 15°.

An attempt was made to determine the intensity of the radiation transmitted at every 10° during a complete rotation of the plate in its own plane. It was not, however, found possible to keep the source of radiation sufficiently constant during the rather considerable time requisite for taking the necessary readings. The results may be most conveniently exhibited by plotting them on squared paper. When this is done and a curve drawn, it is noticed that in the neighbourhood of the maxima and minima of heat transmission an alteration of 5° in the azimuth of the crystal plate makes hardly any difference in the reading of the radiomicrometer, and therefore it may be objected that the sensitiveness of the method is not sufficient to fix within 5° or even 10° the position of the principal vibration directions in the plate. This difficulty can be overcome by comparing pairs of observations at the more sensitive parts of the curve; as, for instance, at 15° and 75° or at 30° and 60°. If the vibration directions of the plate and of the nicols coincide when the reading of the circle is 0°, then the radiomicrometer readings at 15° and 30° must be equal to the readings at 75° and 60° respectively. The following numbers may be quoted in illustration of this point:—

Circle:	15°	30°	60°	75°	105°	120°	135°	150°	165°	195°.
Scale:	$2\frac{1}{2}$	$6\frac{3}{4}$	$6\frac{3}{4}$	$2\frac{1}{2}$	$2\frac{1}{2}$	$6\frac{3}{4}$	$8\frac{3}{4}$	$6\frac{3}{4}$	$2\frac{1}{2}$	$2\frac{1}{2}$

It will be seen that the corresponding readings on each side of the maxima found at 45° and 135°, or taken at equal inclinations to the minima which occur at 0°, 90°, and 180°, exhibit a satisfactory degree of concordance. Had the readings not accorded as shown in the above observations, the directions of the striae would not be those of symmetry-axes, and the true direction of extinction would be in some other position, and could be deduced from the mean of two positions of equal transmission, or by the method described in the next paragraph.

The intensity, I, of the illumination transmitted by a thin crystal plate placed between crossed nicols is given by the expression

$$I = a^2 \sin^2 2\theta \sin^2 \delta/2,$$

where θ is the angle through which the plate has been turned from the position of extinction. This expression must hold for radiant heat as well as for light, and the scale readings of the radiomicrometer are proportional to the heat transmitted. Suppose, then, that the plate is set in a position making an angle θ with the position of extinction and let the scale reading of the radiomicrometer be x divisions. Next let the plate be turned into the position ϕ through a known angle $\phi - \theta = \psi$, and let the corresponding reading of the radiomicrometer be y. We know then x, y, and the angle ψ, and require to calculate θ or ϕ.

We have $\quad a^2 \sin^2 2\phi \sin^2 \delta/2 = yk,$

and $\quad a^2 \sin^2 2\theta \sin^2 \delta/2 = xk;$

hence $\quad \sin 2\phi/\sin 2\theta = \sqrt{y/x}.$

But $\phi = \theta + \psi$,

and $$\frac{\sin(2\theta + 2\psi)}{\sin 2\theta} = \frac{\sin 2\theta \cos 2\psi + \cos 2\theta \sin 2\psi}{\sin 2\theta},$$

whence $\quad \cos 2\psi + \cot 2\theta \sin 2\psi = \sqrt{y/x}.$

We may make ψ any convenient value we please, such as 15°, 22½°, or 30°. If $\psi = 15°$ we have

$$\cos 30° + \cot 2\theta \sin 30° = \sqrt{y/x} \text{ or } \cot 2\theta = 2\sqrt{y/x} - \sqrt{3}.$$

If $\psi = 22\tfrac{1}{2}°$ we have

$$\cos 45° + \cot 2\theta \sin 45° = \sqrt{y/x} \text{ or } \cot 2\theta = \sqrt{2y/x} - 1.$$

If $\psi = 30°$ we have

$$\cos 60° + \cot 2\theta \sin 60° = \sqrt{y/x} \text{ or } \cot 2\theta = 2\sqrt{y/3x} - 1/\sqrt{3}.$$

Thus from two observations the position of extinction may be found. This method has the great advantage that the observations are made at a sensitive part of the curve, and can be so quickly taken that the source of radiation has not time to alter in intensity.

The following example will illustrate the application of this method. The radiomicrometer reading corresponding to a certain position of the crystal plate was 2 scale divisions; on turning the plate through 30° the corresponding reading was 17½ divisions. Substituting, therefore, in the expression $\cot 2\theta = 2\sqrt{y/3x} - 1/\sqrt{3}$ we get

$$\cot 2\theta = 2\sqrt{35/12} - 0{\cdot}5773 = 2{\cdot}839, \text{ whence } \theta = 9°\ 42'.$$

In order, therefore, to put the plate into the position in which its vibration directions coincide with those of the nicols, it must be turned through 9° 42′ in the opposite sense to its former rotation. After making this adjustment it was found that the directions of vibration in the plate coincided with the directions of the striae.

The experiments described above are to be regarded as of a preliminary character only and leave many interesting points unsettled. Thus the wave-lengths of the radiations transmitted by the antimonite have still to be determined, and the refractive indices of the crystal for these radiations measured. The variations in the absorption for rays vibrating in different directions have also to be studied. It will, moreover, be of interest to discover how far the method is applicable to other substances opaque to light. I hope shortly to be able to extend the investigation in these directions, and to improve materially the delicacy of the method by substituting for lime-light either sunlight or the electric arc.