An investigation into the piezo-electric effect of diamond.

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INTRODUCTION.—Opinion is divided as to the true crystal symmetry of diamond. Some authors, notably Fersman and Goldschmidt,[1] who have investigated its morphological and etch characters, consider it is always hemihedral, whilst others, by the same methods, have obtained results which indicate holohedrism. Early work by A. Artom [2] showed that it was seldom piezo-electric, but more frequently pyro-electric. Van der Veen [3] also carried out a very thorough investigation and found no piezo- or pyro-electricity in his five diamonds. These were octahedral in shape, and not very suitable for this experiment.

Two diamonds flattened parallel to the octahedron face, and therefore specially suited to the work, have recently been lent to the Department by the kindness of Mr. Alpheus F. Williams of the De Beers Mines, South Africa, who asked that they should be tested for any piezo-electric effect. It was possible by means of the simple method described below to show that the diamonds were not piezo-electric within the accuracy of the experiment. The essential feature of the method is the way in which pressure is applied to the diamond. As it is most important to maintain the insulated portions quite steady during the application of the force, magnetic attraction was employed rather than mechanical means. This was successful in obviating all but a very slight movement, although the total force obtained in this way was only 300 grams.

Experimental method.—The apparatus (fig. 1) consists of an electro-magnet, on the pole piece of which are placed a plate of amber 1·5 mm. thick and a disk of soft iron 1·25 cm. in diameter and 1 mm. thick. The diamond plate is placed on top of this disk, and on top of the

[1] A. von Fersmann and V. Goldschmidt, Der Diamant. Heidelberg, 1911.

[2] A. Artom, Atti R. Accad. Sci. Torino, 1902, vol. 37, p. 667.

[3] A. L. W. E. van der Veen, Zeits. Kryst. Min., 1913, vol. 51, p. 545.

diamond a long pole piece which is attracted downwards when the current is passed through the coils of the magnet. A long pole piece is necessary because in this way a much greater force is obtained. In these experiments a current of 4 ampères was used, and this gave a force of attraction of about 300 grams between the upper pole piece and the magnet when the diamond was in position. To measure the charge developed on switching on the current, it would at first sight seem sufficient to connect the upper pole piece to the electrometer and the lower disk to earth. Then if there should be any charges developed due to causes other than the piezo-electric effect it would seem that they could be eliminated by reversing the diamond. It was found that this simple method was not adequate to differentiate between the causes contributing to the deflexion in any given case. These are partly due to slight irregularities on the surface of the diamond and pole piece, giving rise to a very slight 'wobble'. If this were the same for the diamond both in its first position and also when reversed it would not matter; but since this cannot be so, it is necessary to devise a means of eliminating this effect. This difficulty can be expressed symbolically as follows. If D is the effect of the diamond and W_1 the deflexion due to the 'wobble' in the first position, $-D$ will be the effect when the diamond is reversed and W_2 the second wobble. Then the deflexions, x_1, x_2, will be given by

$$x_1 = D + W_1 \text{ and } x_2 = -D + W_2.$$

It is clear that since we have two equations and three unknowns, the value of D cannot be found. To overcome this difficulty the amber plate and lower electrode indicated in the figure were introduced. Wires from the upper and lower electrodes were joined alternately to the electrometer, which was of the sensitive Compton type, by means of two mercury cups. The method of conducting an experiment was as follows. With the diamond in its first position three deflexions were measured: (*a*) with the upper pole piece connected to the electrometer and the lower connected to earth; (*b*) the lower pole connected to the electrometer and the upper to earth; (*c*) both electrodes connected to the electrometer. The diamond was then reversed and these three observations repeated. There are thus six observations in all for each measurement of the piezo-electric effect, which are combined in the following way. The 'wobble' need not be the same for the diamond in its two positions, and hence it is necessary to allow for two values, W_1, W_2. In addition to the 'wobble', there is a small induced effect independent of which electrode happens to be connected to the electrometer. This may be different for the diamond in its two positions, and therefore two terms, X_1, X_2, are introduced to take account of this. Lastly, the amber which is used to insulate the lower iron disk from the magnet may give rise to a constant piezo-electric effect, independent of everything except the total pressure applied, and this is denoted by A.

We may thus write down a series of equations connecting these

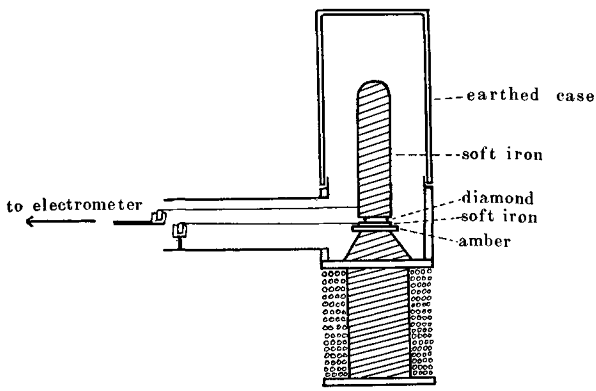

FIG. 1. Diagram of apparatus for testing piezo-electric effect.

constants with the six observed deflexions. With the diamond in one position and the upper electrode connected to the electrometer, we have

$$x_1 = D + W_1 + X_1.$$

When the lower electrode is joined to the electrometer, then

$$x_2 = A - D + X_1,$$

and when both electrodes are connected together

$$x_3 = A + W_1 + X_1.$$

For the diamond in its reversed position we have a similar set of three equations, the sign of D being reversed and W_2, X_2 substituted for W_1, X_1.

$$x_4 = -D + W_2 + X_2;$$
$$x_5 = A + D + X_2;$$
$$x_6 = A + W_2 + X_2.$$

With these six equations we can solve the equations for the six unknowns, including the value of D.

Experimental results.—One of the diamonds used for the experi ments is a plate 0·121 cm. thick, the large face being parallel to the octahedron, and it is apparently untwinned. It is lozenge-shaped, the maximum length being 10 mm. and the minimum 8 mm. Under the polarizing microscope it appears to be quite isotropic and also shows some small triangular markings having their edges inclined at 60° to the octahedron edges. The second is a spinel-twin 0·219 cm. thick, the large face being parallel to the octahedron. It is triangular in shape, the length of the side being 8 mm. Under the polarizing microscope this specimen shows anomalous double refraction.

Owing to the minute electrical effects concerned in these experiments it was necessary to use the electrometer in as sensitive a condition as convenient, which was found to be 7,000 divisions per volt. With 4 ampères circulating in the electromagnet the deflexion obtainable with the quartz section was 460 mm. Six sets of observations were made on the thin diamond, and the maximum deflexion found for it after applying the reduction given by the six equations above was 1·3 mm. The experimental error cannot be determined accurately, but is probably about 2 mm. Three sets of observations were made on the other diamond. In this case, because of the smaller area of its octahedron face, it was much more difficult to avoid 'wobble'. The maximum value of D was found to be 5 mm., and the experimental error was about the same value. Thus we may conclude that within the limit of error the diamond shows no piezoelectric effect, and that if there is an effect it is less than 1/200th part of that of quartz cut perpendicular to an electric axis.

Discussion.—The hemihedral character of diamond has been investigated by a number of methods. Fersman and Goldschmidt (op. cit.), in their treatise on the diamond, come to the conclusion that the diamond is certainly hemihedral, basing their arguments on morphological and etch characters. In some unpublished work, Mr. Alpheus F. Williams has shown by the same methods that the diamond is not necessarily hemihedral. Mrs. K. Lonsdale[1] has recently shown that the crystal structures of many of the carbon compounds, and also of carbon in the free state, can be explained on the assumption that the carbon atom has two different types of valency. If this be true it is probable, though not certain, that the diamond would show piezoelectric effects. Elings and Terpstra[2] have recently investigated the

[1] K. Lonsdale (née Yardley), Phil. Mag., 1928, ser. 7, vol. 6, p. 433.
[2] S. B. Elings and P. Terpstra, Zeits. Krist., 1928, vol. 67, p. 279.

piezo-electric effect in diamond and many other compounds by a method involving triode valves and they observed no effect for diamond. I have also carried out a similar experiment with diamond with like result. The measurements of van der Veen [1] showed that the effect in his diamonds could not be greater than 1/600th of that in quartz. The experiment described here, though not so sensitive, indicates that the effect must be of the same order if it exists at all. Therefore, in conclusion, we may say that some physical properties of the diamond demand holohedral characters and that all others can be reconciled with that symmetry.

I wish to thank Mr. Alpheus F. Williams for the loan of the diamonds, Mr. E. C. Bullard for assistance in some of the experimental work, and Mr. N. Lanham for the preparation of the quartz section. This section, used for comparison, was 0·10 cm. thick and was cut perpendicular to an electric axis.

[1] A. L. W. E. van der Veen, Zeits. Kryst. Min., 1913, vol. 51, p. 545.