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*The graphitization of diamond and the nature of
cliftonite.*

(With Plate XXVI.)

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[Read January 24, 1952.]

1. *Introduction.*

IT has long been known that if a diamond is heated in pure oxygen, or even in air, to a temperature of about 700° C. or higher (depending on the initial quality of the diamond), it will be wholly or partially oxidized to CO or CO₂, but that if the diamond is heated in the absence of oxygen—preferably in vacuo—to a temperature of about 1500° C. or higher (again depending on the initial quality of the diamond), it will be wholly or partially converted to graphite. For complete conversion the graphite is always polycrystalline. The *partial* conversion of diamond to graphite is, however, of considerable interest, because when graphite forms on a single crystal of diamond it exhibits a strong preferred orientation. It was hoped by the study of such graphitized diamonds to obtain information on the following four questions:

(a) *The origin of cliftonite.*—The detailed investigation of this preferred orientation was undertaken mainly because of an interest in the formation of the mineral cliftonite. This is a graphite of *cubic* habit which is found in some meteorites, and it has been studied by several investigators, mainly, however, before the development of X-ray crystallography—references to this early work can be found, for example, in a book by A. E. Fersman and V. Goldschmidt.¹ It has been conjectured

¹ A. von Fersmann [A. E. Fersman] and V. Goldschmidt, *Der Diamant*. Heidelberg, 1911. [Min. Mag. 16-164.]

that cliftonite is a pseudomorph after diamond, but a single X-ray photograph published by M. H. Hey¹ made this appear very unlikely, and it was therefore decided to make direct comparative experiments to test the hypothesis, the necessary detailed examination of cliftonite being made at the same time.

(b) *The origin of the graphite on graphite-coated diamonds.*—Diamonds coated with a thin layer of graphite are found in the Premier diamond mine, South Africa,² and might have originated (i) by direct crystallization of additional carbon on the diamond crystal after the conditions favouring the formation of diamond had altered, or (ii) from the conversion of the surface layers of the diamond to graphite due to a subsequent increase in temperature, or other appropriate change. Hence, if the orientation of the graphite could be determined on both naturally and artificially graphitized diamonds, this point might be cleared up.

(c) *The nature of the graphite produced when diamond is graphitized.*—There are two recognized forms of graphite;³ in the common form successive hexagonal layers of carbon atoms can be thought of as being related to each other by hexagonal close-packing (2-layer structure), while in the rare form successive layers are related as in cubic close-packing (3-layer structure, space-group $R\bar{3}m$). The rare form seems to be present to the extent of about 4–14 % in different natural and artificial graphites, and the percentage can sometimes be increased by mechanical working⁴ or decreased by chemical action (Lipson and Stokes, loc. cit.).

Now, if a diamond is thought of as consisting of a series of hexagonal 'aliphatic' layers normal to the trigonal axis, the structure will be analogous to that of the rare form of graphite, in which the layers are 'aromatic' but arranged in the same way. Thus, if a diamond is converted to graphite, it is possible that such graphite would be mostly, if not exclusively, of the rare form. This was indeed suggested by Nath,⁵ but he did not quote experimental evidence in support of his view that this was the transition structure between graphite and diamond, and direct evidence is still required.

(d) *The possibility of altering diamond by heat-treatment.*—Diamond is

¹ M. H. Hey, *Min. Mag.*, 1938, vol. 25, p. 81.

² P. A. Wagner, *Trans. Geol. Soc. South Africa*, 1915, vol. 17 (for 1914), p. 29.

³ H. Lipson and A. R. Stokes, *Proc. Roy. Soc. London, Ser. A*, 1942, vol. 181, p. 101. [M.A. 8-284.]

⁴ G. Bacon, *Acta Cryst.*, 1950, vol. 3, p. 137. [M.A. 11-235.]

⁵ N. S. N. Nath, *Proc. Indian Acad. Sci., Sect. A*, 1935, vol. 1, p. 841. [M.A. 6-200.]

extremely resistant to chemical attack, and cannot be plastically deformed, at least not under laboratory conditions, and from the experimental point of view it would be very useful if diamond could be altered in a reproducible way; in particular if Type I could be changed into Type II, and vice versa. Heat-treatment suggests itself as a possible method of effecting such alterations, and partially graphitized diamonds will almost certainly be a by-product of any such experiments.

2. *Experimental material.*

In order to gain a general idea of the type of results to be expected, X-ray photographs were taken of a number of diamonds which had been subjected to various kinds of heat-treatment (kindly lent to me by Mr. P. Grodzinski), although the nature of diamonds before treatment was, from an X-ray standpoint, unknown.

Attempts were also made to graphitize diamonds in a carbon arc, and several diamonds were successfully graphitized in a vacuum furnace.

Graphite-coated diamonds from Premier mine, and samples of Fletcher's original batch of cliftonite were made available by the British Museum.

3. *Experimental results and discussion.*

(a) *The preferred orientation of the graphite.*—In this work only the (0002) graphite ring obtained with Cu- $K\alpha$ radiation has been studied, i.e. information has been sought on the orientation of the *hexagonal* axis of the graphite relative to the main crystal. The chart in fig. 1 shows the appearance on a stereographic projection of a small circle of radius $[90^\circ - \theta_{(0002)}]$ —originally parallel to the plane of projection—rotated through successive intervals of 5° about the 90 – 90° vertical line of the diagram. It is a useful time-saving device when plotting the pole-figures from the X-ray photographs. A pole-figure frequently shows some symmetry, and then only a limited section of the sphere need be investigated. In both cases considered here the symmetry is $m3m$, and thus if the crystal is mounted with [001] vertical and rotated over a range of 45° , starting with the X-rays along [100], the whole pattern can be obtained.

(i) *Graphitized diamond.*—The preferred orientation of the graphite formed on a *cube* and on an *octahedron* was *geometrically identical*, allowance being made for the larger quantity of graphite present on the cube. Representative Laue photographs are shown in fig. 2. Further, the orientation was relatively sharp, as can be seen from the pole figure in

fig. 3A. It seems, therefore, that the formation of graphite on diamond, at least in vacuo, is, as had been anticipated, *characterized by the association of the hexagonal axis of the graphite with the trigonal axis of the diamond; and is independent of the habit of the diamond.*

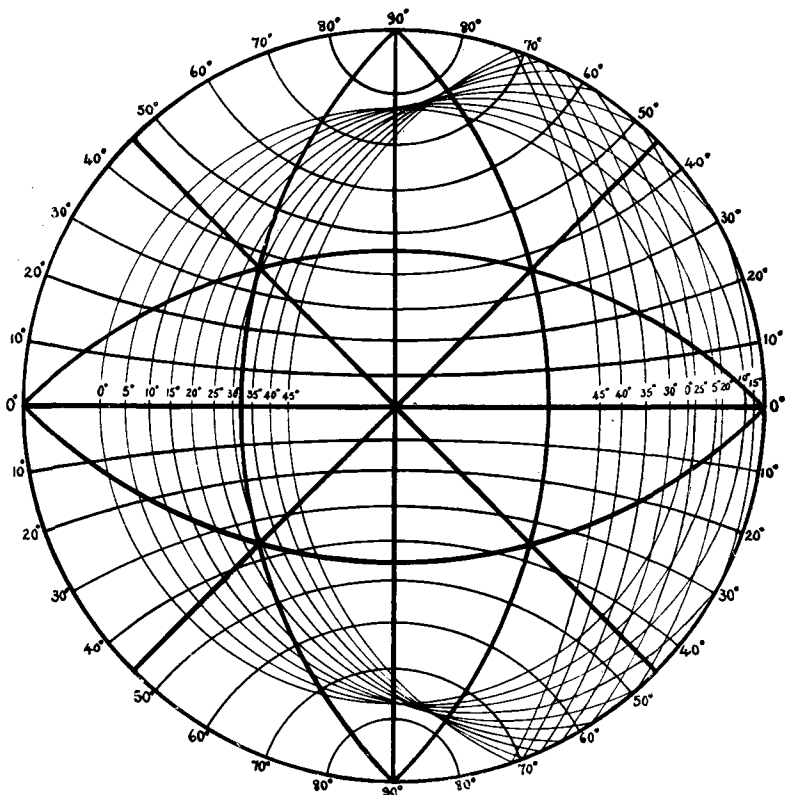


FIG. 1. Chart for the determination of the preferred orientation of graphite found for cliftonite and heat-treated diamonds. [$\text{Cu-K}\alpha$ and (0002): i.e. $\theta = 13.2^\circ$.] The cubic symmetry of the substrate results in the preferred orientation diagram having planes of symmetry as shown by the heavy lines, and thus rotation about [001] over a range of 45° , starting with the X-ray beam along [100], is sufficient for the determination of the complete pattern.

This independence was not necessarily to be expected; since graphite is a tabular crystal, it was quite possible that it would simply form plates on whatever surface of diamond was available, and hence the association of the [0001] axis with the trigonal axis of an octahedron would have been expected anyway. The naturally occurring graphite-coated dia-

monds are reported to show flakes or plates of graphite on their surfaces, which could be in accordance with this hypothesis. In this case, however, *cubic* diamonds would have to show the [0001] axis associated with the

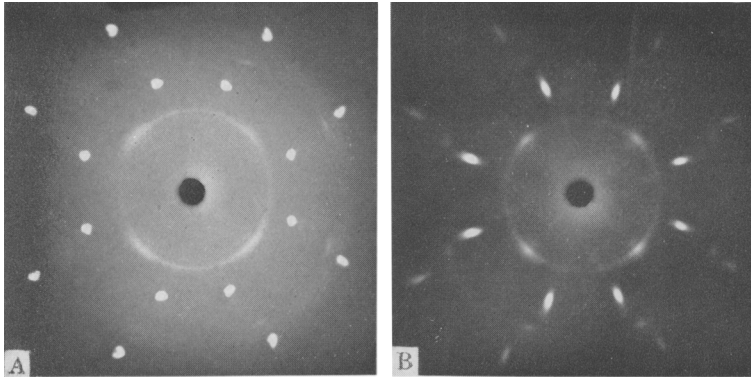


FIG. 2. Laue photographs ($\times 0.8$) of diamond: A, octahedral crystal; B, cubic crystal.

[001] vertical, X-ray beam along [100], crystal 2.5 cm. from film. Filtered copper radiation, 30 kV, 15 mA, $\frac{1}{2}$ hour.

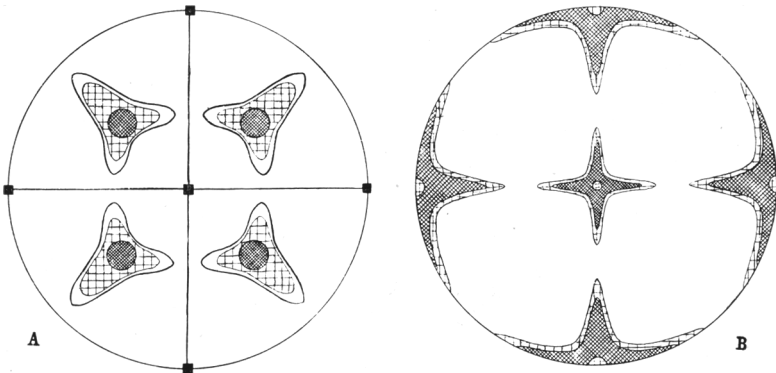


FIG. 3. Pole figures showing the preferred orientation of graphite (0002) in: A, Diamond graphitized by heating. B, Cliftonite from the Younegin meteorite.

cube axes. Accordingly, some natural cubes of Belgian Congo diamond of edge approx. 1 mm. (the smallest which could be obtained) were kindly made available for this work by A. Triefus & Co., to whom I am grateful for this courtesy. It was while preliminary photographs of these specimens were being obtained prior to heat-treatment in order to

establish the presence or absence of anomalous reflections¹ that the spontaneous divergent-beam pattern was discovered.²

(ii) *Cliftonite*. Sir Lazarus Fletcher³ isolated (1887) from the Youndeggin meteorite about 100 crystals, averaging 0.2 mm. edge, which were of cubic habit and had the chemical properties of graphite. He made a careful morphological examination of these crystals and endeavoured (1899) unsuccessfully to find more of them. Further specimens have,

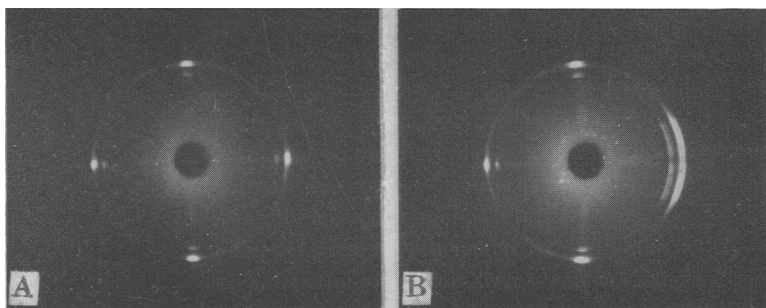


FIG. 5. Laue photographs (same size) of cliftonite from the Youndeggin meteorite. Specimens 2.5 cm. from film, [001] vertical. 30 kV, 15 mA, $\frac{1}{4}$ hour. A, filtered copper radiation, X-ray beam along [100]. B, unfiltered copper radiation, X-ray beam at 10° to [100].

however, been located in other meteorites. The X-ray rotation photograph published by Hey (loc. cit.) in which one of these crystals was mounted with a cube edge vertical, showed that the crystal was indeed graphite, and that there was some indication of preferred orientation of the [0001] axis along the cube axes of the crystal (a similar photograph is shown in fig. 4A, pl. XXVI, and a powder photograph of natural graphite is shown in fig. 4B, pl. XXVI for comparison). This was not the orientation that would have been expected for diamond, and so several crystals of cliftonite were kindly lent to me by the Mineral Department of the British Museum in order to confirm or extend this X-ray analysis. Hey's result was confirmed for all ten crystals examined, and indeed on Laue photographs the preferred orientation was found to be even sharper than he had thought (fig. 5A). A specimen of good cubic form was set visually with a [100] axis vertical, and a systematic preferred orientation determination was made. The resulting pole figure is shown in fig. 3B.

¹ K. Lonsdale, Proc. Roy. Soc. London, Ser. A, 1942, vol. 179, p. 315. [M.A. 8-284.]

² H. J. Grenville-Wells, Nature, London, 1951, vol. 168, p. 291.

³ L. Fletcher, Min. Mag., 1887, vol. 7, p. 121; 1899, vol. 12, p. 171.

The difference between this and the corresponding diagram for graphitized diamond (fig. 3A), even of cubic habit, is striking. In fact, unless the preferred orientation found for diamond is strongly dependent on the conditions of graphitization, and these are very different in the meteorite from anything obtainable in the laboratory (as well they might be), there does not seem to be the slightest possibility that cliftonite is a pseudomorph after diamond. A definite conclusion on this point cannot,

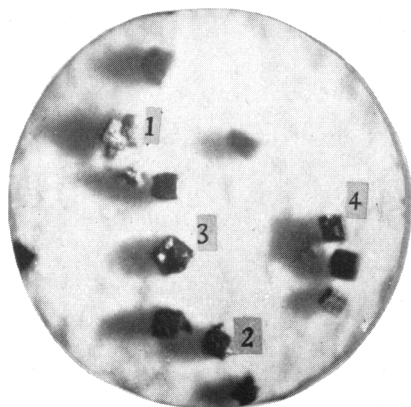


FIG. 6. Cliftonite from the Youndegin meteorite, Western Australia. $\times 20$.

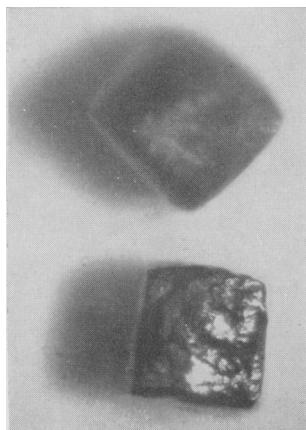


FIG. 7. Graphitized diamond cubes. $\times 20$.

however, be reached until suitable natural graphite-coated diamonds have been examined.

The morphology of the cliftonite is also rather peculiar. Several crystals are shown in fig. 6, and the two graphitized diamond cubes are shown in fig. 7 for comparison. Most of the features noted by Fletcher can be seen in fig. 6; firstly, many of the crystals carry globular or acicular projections (1, 2). An interpenetrating twin of two cubes (the fluorite type) can be seen at (3), and one crystal in which faces of the form $\{hk0\}$ appear to have developed can be seen as well (4). Fletcher also reported that some of the crystals were hollow, and all the X-ray photographs obtained in this work show the (0002) ring split, as can be seen in fig. 5B—particularly in the Cu- $K\beta$ powder ring. This could be reproduced artificially by mounting a small quantity of graphite powder in seccotine *round* the end of a glass fibre, so that the graphite was effectively in the form of a hollow tube; thus the hollowness of the crystals might

be a general phenomenon, as suggested by the low density of the cliftonite (~ 2.12 gm./c.c.) as compared with that of graphite, and this certainly provides the simplest explanation of the split (0002) reflection.

Another interesting peculiarity is the weakening of the preferred orientation in the region of about 2° in all directions about the $\langle 100 \rangle$ directions, as can be seen in fig. 5B; such an effect is known in other meteorite minerals which are regarded as pseudomorphs (information supplied by Dr. M. H. Hey).

The one point of similarity between the graphitized diamond and the cliftonite is that in both cases the (0002) reflection is very sharp, whereas the second ring is relatively diffuse, and there are no sharp rings at angles approaching $\theta = 90^\circ$. The nature of the graphite itself does thus appear similar in the two cases.

No alternative explanation of the origin of cliftonite has been found. The possibility that anything of this type is to be found in nickel-iron alloys of composition similar to that in the meteorite is exceedingly remote (H. G. Morrough, private communication), so that it seems almost certain that it is a pseudomorph of some kind and not a spontaneous formation. It might be profitable to re-examine some meteoritic diamonds to see whether there is any incipient graphitization, and if possible to graphitize diamond at very high pressures.

(b) *Graphite-coated diamonds from Premier mine, South Africa.*—A. F. Williams¹ states that 'Graphite-coated diamonds are found in every mine, but are more common in some mines than others. Especially well-preserved specimens are of quite common occurrence in the Premier mine.' Williams goes on to describe a number of specimens in detail, but no information which enabled a decision to be reached on the method of formation was obtained, apart from the fact that the graphite showed great chemical refractoriness, which suggested that it has been formed at a very high temperature (Wagner, loc. cit.).

Two such specimens kindly lent to me by the British Museum were examined by X-rays. Unfortunately these were large crystals (about 6 mm. diameter) and thus rather unsuitable for X-ray work, but no others were available. One specimen (B.M. 1910,222, weight 0.368 gm.) is an octahedron. Laue photographs showed that this diamond, while mainly a monocrystal, is of very poor quality and showed some fragmentation. No trace of graphite could be detected on an exposure of

¹ A. F. Williams, *The genesis of the diamond*. London, 1932, vol. 2, p. 434. [M.A. 5-97.]

1 hour at 15 mA. Similar results were found in cases of artificial graphitization (or attempted graphitization) as mentioned in section (d) below.

The other specimen (B.M. 1910,223, weight 0.430 gm.) of irregular shape though it has roughly the form of a cube modified by a form $\{hk0\}$, was set in what was assumed to be an orientation in which the X-ray beam would coincide with a fourfold axis. The resulting photograph is shown in fig. 8, and it is curious that with such complete absence of discrete Laue spots there is not a greater development of diamond powder rings. This indicates that the specimen was originally a monocrystal, and not a randomly oriented collection of crystallites like carbonado. As can be seen, there is again no trace of a graphite powder ring. The general appearance of some of the patches of small spots is, however, very similar to those obtained on photographs of gem diamond which has been graphitized (section (d) below), although in fig. 8, pl. XXVI, the process has obviously been carried very much farther. The failure to observe graphite on these specimens is disappointing, and it is hoped that some small crystals really suitable for X-ray examination will be obtainable.

(c) *The nature of the graphite formed.*—It can be seen that the graphite itself is of a somewhat unusual form. The strongest lines of the normal graphite powder pattern are visible and are indexed in table I.

TABLE I. Indexing of X-ray photograph of cliftonite (fig. 4A, pl. XXVI).

hkl	Sharpness (visual estimate).	θ_{hkl} (calc.)	θ_{hkl} (obs.)
0002	sharp (split)	13.30°	13.31°
1010	quite sharp	21.22	21.24
$10\bar{1}\frac{2}{3}$	quite sharp	21.72	21.81
1011	not defined	22.32	—
$10\bar{1}\frac{4}{3}$	not defined	23.16	—
0004	slightly diffuse	27.40	27.37
1120	very sharp	38.83	38.80
1122	rather diffuse	41.94	41.82
0006	rather diffuse	43.65	43.52
2020	very diffuse	46.43	—
$20\bar{2}\frac{2}{3}$	lines not resolved	46.76	~ 46.73
2021	—	47.18	—
$20\bar{2}\frac{4}{3}$	—	47.77	—
1124	very diffuse	53.37	~ 50.97

The Bragg angles were calculated using Lipson and Stokes' values of the lattice constants, i.e. a 2.456, c 6.696 Å., and the wave-length of Cu-K α radiation 1.541 Å. The measured values were obtained from fig. 4A, pl. XXVI. The excellent agreement obtained is to some extent fortuitous,

as no corrections have been applied. The 0006 reflection is probably visible only because of the strong preferred orientation which gives it enhanced intensity at the equator. No lines having higher θ -values can be detected.

The resolution obtainable with a 3 cm.-radius camera is not really sufficient to warrant a detailed analysis of the powder pattern, but by comparing the original negatives of the cliftonite and of natural graphite the most important difference can be seen to lie in the group of four closely spaced lines $10\bar{1}0$, $10\bar{1}\frac{2}{3}$, $10\bar{1}1$, and $10\bar{1}\frac{4}{3}$. In natural graphite, $10\bar{1}1$ is considerably stronger than the other three (as can be seen in fig. 4B), whereas in cliftonite $10\bar{1}0$ and $10\bar{1}\frac{2}{3}$ are clearly defined while $10\bar{1}1$ and $10\bar{1}\frac{4}{3}$ do not appear as discrete lines at all, although there is quite a strong broad diffuse ring in this region. (This detail does not reproduce clearly in the photographs.) As pointed out by Lipson and Stokes (*loc. cit.*) the sharpness of the $11\bar{2}0$ reflection indicates that the hexagonal layers themselves remain perfect.

The relative prominence of $10\bar{1}\frac{2}{3}$ might seem to be an indication that the proportion of β -graphite present is higher than usual, in accordance with Nath's hypothesis, but $10\bar{1}\frac{4}{3}$, which is also a β -graphite reflection, does not appear as a discrete line. An arrangement of layers which would account for the observed diffraction effects has not yet been worked out. This particular pattern does not approximate to any of the photographs published by Miss Franklin¹ for graphite of varying probabilities of disorientation between successive layers.

(d) *Effect of heat-treatment on the diamond itself.*—The formation of graphite could just be detected by means of X-rays on one blackened octahedron (treatment unspecified). This specimen showed no anomalous streaks, and a fairly strong spontaneous divergent beam pattern. No graphite could be detected on a Laue photograph of 1 hour's exposure at 15 mA for a large diamond which had been raised to 1820° C. in 2½ minutes and then allowed to cool, although it was completely blackened.

(i) *Diamonds heated to 2000° C. in a carbon block.*—Three diamonds which had been raised to 2000° C. in two minutes were much blackened and broken, and fragments of these were tested. All gave strong graphite powder patterns, in which the 0002 ring in particular showed strong preferred orientation, in addition to the diamond pattern. A Laue photograph of one piece showed, instead of sharp Laue spots, collections of small spots which sometimes lay on short lines radiating from a centre and indicating that the breaking-up of the crystal had not been entirely

¹ R. E. Franklin, *Acta Cryst.*, 1951, vol. 4, p. 253.

random. The fine structure of these Laue spot groups was not investigated.

A small fragment in the form of an octahedral plate gave a divergent-beam photograph (using an iron foil)¹ which showed very fine lines, and produced very good sharp Laue spots, although irregular patches near the strongest reflections showed that there had been some breaking-up of the crystal. In all these photographs it could be seen in a general way that the preferred orientation of the graphite 0002 reflection was associated with the diamond [111] axes.

Another fragment in the form of an octahedral plate showed quite strong anomalous reflections (Lonsdale, loc. cit.), and it could be seen from the Laue spots that again the main portion of the diamond had remained a good monocrystal. A complete series of photographs for the examination of these extra reflections was taken with Cu radiation.

(ii) *Diamonds heated in a carbon arc.*—Through the kindness of Mr. B. W. Anderson in providing the necessary facilities, experiments were made on the possibility of graphitizing diamonds directly in a carbon arc. Gem octahedra were placed in a shallow recess in a carbon block and held for periods of up to five minutes in a carbon arc, where they could be seen glowing almost as brightly as the arc itself, and must have reached a high temperature. They were completely blackened, but a specimen which had previously shown strong extra streaks still did so, and showed no traces of graphite on a photograph of moderate exposure; however, an iron-foil divergent-beam photograph showed the development of an extremely fine sharp (111) conic, which is not usual for perfect diamonds, and may indicate that some breaking-up of the crystal had occurred. One diamond octahedron which had become partially blackened did, however, show some X-ray evidence of graphite formation.

These experiments indicated that diamond could not be satisfactorily graphitized in a carbon arc, partly because the temperature reached could neither be measured nor controlled, and partly because the heating took place in the presence of oxygen, which favours the formation of CO or CO₂ rather than of graphite. These experiments were therefore not pursued farther.

(iii) *Diamonds heated in a vacuum furnace.*—A special vacuum furnace small enough to be heated in an arc, and whose temperature could be controlled and measured, was designed for experiments of this kind by Dr. E. Billig, to whom I am greatly indebted for the time and trouble he has spent on the graphitization of diamonds for this investigation.

¹ H. J. Grenville-Wells, Thesis, London University, 1951.

Preliminary tests to determine suitable conditions of graphitization were made on five gem octahedra and two Congo cubes. It is the results on this batch which are discussed here, further experiments having been unavoidably delayed. Diamonds sawn to provide (100) and (110) planes in addition to natural (111) faces will also be graphitized to test the relative ease of graphitization of different crystallographic surfaces.

As can be seen in fig. 2A the gem octahedron has retained its monocrystalline form and still gives sharp Laue spots. It gives a weak, sharp divergent-beam picture. The two cubes, on the other hand, have altered very strikingly. Fig. 9, pl. XXVI, shows an iron-foil divergent-beam photograph of such a diamond before heat-treatment, and fig. 10, pl. XXVI, shows one of the cubes after heating to 2000° C. (both cubes give exactly the same type of photograph). Here the Laue spots are quite diffuse, and the divergent-beam conics are much less well-defined, although outwardly the crystals do not appear to have altered, except that they are blackened.

These cubes were quite opaque and strongly coloured before treatment. It is therefore possible that they contained impurities which have either altered or been driven off at the high temperature, and this has caused the complete deterioration of the crystal. Further experiments with Congo diamonds would be of interest. Although Fe and Si were found in two such cubes by spectrographic analysis (carried out by Miss Czapska of Hilger's Ltd., to whom I am much indebted for doing this), other Congo diamonds have been shown to contain different impurities, and it would be unwise to generalize about the influence of impurities.

As regards the original intention to see whether heat-treatment could transform Type I diamond¹ into Type II, or vice versa, it certainly proved possible to increase the mosaicity of the diamonds, but the experiments met with no success whatever in affecting the intensity of the anomalous streaks. The position in this respect may be summarized as follows:

Extra streaks were not observed to appear in any diamond from which they had previously been absent; i.e. we could not turn a Type II (mosaic) diamond into a Type I (perfect) diamond by some kind of annealing process. This does not necessarily mean that this is impossible, because the heat-treatment used was a violent one of rapid heating followed by immediate cooling, and was probably quite unsuitable for such annealing.

¹ R. Robertson, J. J. Fox, and A. E. Martin, *Phil. Trans. Roy. Soc. London. Ser. A*, 1934, vol. 232, p. 463. [M.A. 6-6, 494.]

Diamonds (whose previous quality was unknown from an X-ray standpoint) which had been heated to 2000° C. and showed appreciable graphite-formation and fragmentation, also showed quite strong extra effects, and sharp Laue spots indicating that the greater part of the specimen was still a good single diamond crystal. A complete set of Laue photographs indicated that the extra reflections were of the usual type, though satellite reflections resulting from fragmentation made it difficult to see them properly.

Gem diamonds which had originally shown strong extra streaks and which after graphitization showed the development of divergent beam conics, indicating that their texture had become increasingly mosaic, still showed undiminished extra streaks. This persistence is a strong indication that the anomalous streaks are not some kind of perfect-crystal effect, but represent some defect structure which is not appreciably affected by heating.

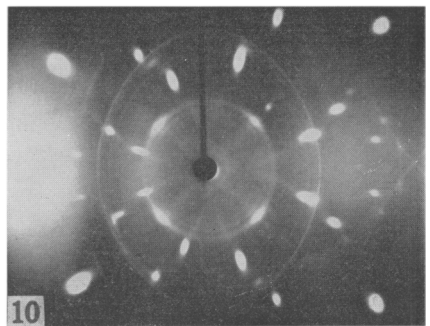
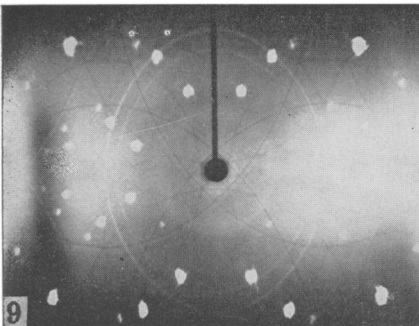
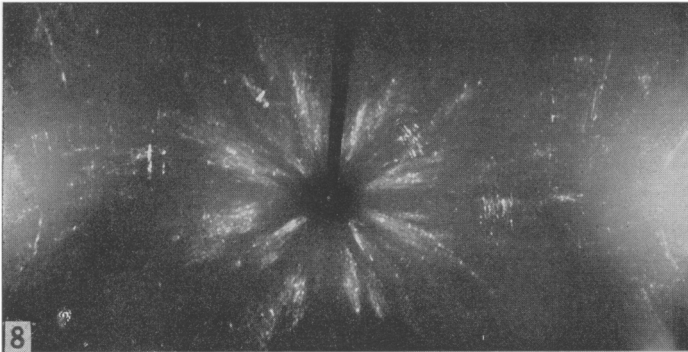
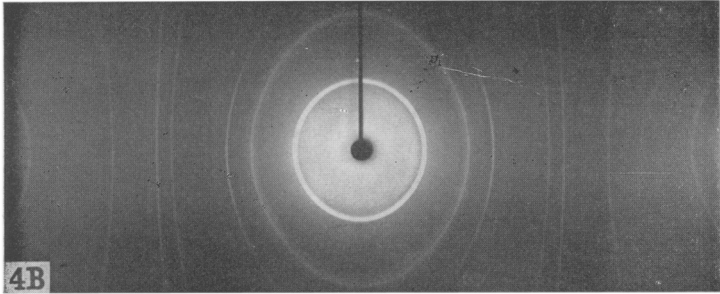
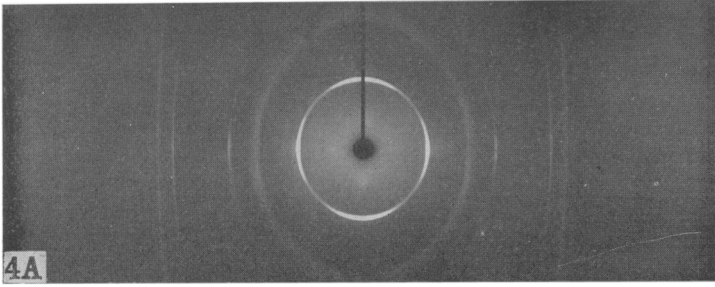
Acknowledgements.—In addition to the acknowledgements made in the text, I am indebted to Dr. W. Campbell Smith, Dr. F. A. Bannister, and Dr. M. H. Hey of the Mineral Department of the British Museum for their interest in this work and for helpful discussions. I should like to thank the Diamond Corporation for the provision of a collection of gem diamonds from which some of these specimens were taken; and Industrial Distributors (1946), Ltd., for financial assistance enabling me to undertake the research of which this work forms part. Finally, it is a pleasure to record my gratitude to my supervisor, Professor Kathleen Lonsdale, for much valued advice and encouragement during the course of this work.

Summary.—Diamond heated in vacuo to about 2000° C. is wholly or partially converted to graphite which has a strong preferred orientation, the [0001] axis of the graphite being associated with the diamond [111] axis irrespective of the original habit of the diamond. The preferred orientation of the graphite in cliftonite, however, has been shown to involve the association of the [0001] axis with the cube axes of the crystal, thus casting doubt on the possibility that cliftonite is a pseudomorph after diamond. The graphite itself appears in both cases to be imperfectly crystallized, and is neither α - nor β -graphite, nor the usual mixture of the two. It has been shown by means of divergent-beam X-ray photographs that the mosaicity of diamonds can be increased by heat-treatment.

EXPLANATION OF PLATE XXVI.

X-ray photographs ($\times 0.62$) of diamond, graphite, and cliftonite.

- FIG. 4A. Cliftonite from the Youndegin meteorite, Western Australia. Rotation photograph with [001] vertical. Filtered copper radiation, 30 kV, 15 mA, $3\frac{1}{2}$ hours.
- FIG. 4B. Natural graphite, Powder photograph. Filtered copper radiation, 30 kV, 15 mA, $3\frac{1}{2}$ hours. Specimen rotated.
- FIG. 8. Graphitized diamond from Premier mine, South Africa. Cylindrical Laue photograph, radius 3 cm., X-ray beam along [100]? Brass target, Cu-Zn radiation, 45 kV, 10 mA, 2 hours.
- FIG. 9. Diamond, cube from Belgian Congo. Cylindrical Laue photograph, radius 3 cm. [001] vertical, X-ray beam along [100]. Copper radiation with iron foil, 30 kV, 15 mA, 2 hours.
- FIG. 10. Diamond, cube from Belgian Congo. After being heated to 2000° C. Cylindrical Laue photograph, radius 3 cm. [001] vertical, X-ray beam almost along [100]. Copper radiation with iron foil, 30 kV, 15 mA, $1\frac{1}{4}$ hour.
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H. J. GRENVILLE-WELLS: X-RAY PHOTOGRAPHS OF DIAMOND,
GRAPHITE, AND CLIFTONITE