ON THE FUSION OF CARBON.

By O. P. Watts and C. E. Mendenhall.

In a recent number of the Annalen, LaRosa[1] has described some experiments on the bending of carbon rods at high temperatures and has submitted this bending, together with certain peculiar surface appearances which he observed, as evidence for the existence of a true fusion point for carbon at ordinary pressures. It seemed to the writers that before accepting LaRosa's interpretation of his bending effects it would be well to make further tests with two points especially in mind, namely:

1. To compare the properties of graphite and carbon at high temperatures, to determine whether the bending was due to the traces of binding material (some hydrocarbon) remaining in the carbon, or whether it occurred equally well with graphite, from which the binder might naturally be supposed to have been largely removed by the prolonged and intense heating to which it had been subjected in manufacture.

2. To determine at least approximately the temperatures at which bending occurred, in order to decide whether it really indicated incipient fusion or whether it was merely an evidence of increasing plasticity at high temperatures.

Fortunately we had available a dynamo capable of giving continuously 600 amperes at 110 volts, direct current, so that we could use larger rods than LaRosa, and approach the bending stage gradually, giving ample time for the making of temperature observations on the rod with a Holborn-Kurlbaum type of optical pyrometer. Such observations give directly, of course, only the "black" temperature of the rods; to convert to true temperature we have used results connecting the "black" and "true" temperatures of carbon, shortly to be published by one of us.[2] We have made many tests upon rods 6 mm. in diameter, and 15 cm. and 30 cm. long, the material being (*a*) ordinary commercial carbon made by the National Carbon Co., Cleveland, O., U. S. A.; (*b*) an exceedingly fine-grained high-grade German carbon (Conradty) probably very similar to the material used by LaRosa; and (*c*) the purest graphite

[1] M. LaRosa, Ann. der Physik, No. 1, 1911, p. 95.

[2] Above 2000° C. the determination of this correction requires extrapolation of an empirical curve, so that the highest temperatures may be in error 50 or 75 degrees.

made by the Atcheson Graphite Co., Niagara Falls, N. Y. We produced bending either by pushing one electrode toward the other, or by rotating one electrode around a pivot near the center of the rod, or by hanging a weight on two equal rods clamped near to and parallel to each other and connected at their free ends.

Our results may be briefly summarized as follows:

1. American carbon takes a permanent bend most readily (Fig. 1, No. 3), German carbon next, and graphite with greatest difficulty. This

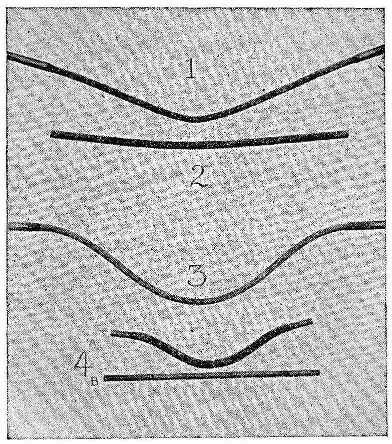

Fig. 1.

No. 1. Graphite. Angle of 50°. Max. temperature = 2770° C.
No. 2. Graphite. Broke hot, while bent 55° at center. 2630° C.
No. 3. Carbon. Angle 75°. Temperature 2600° C.
No. 4A. Rod expanded by carbon vapor. 2900° C.
No. 4B. Original size of rod.

is in the order of increasing purity, and decreasing amount of binding material. Nevertheless we easily obtained even with graphite more pronounced bending than any shown by LaRosa—as for example a sharp bend of 50° in the middle of a 30 cm. graphite rod (Fig. 1, No. 1) produced in four minutes at a temperature between 2700° and 2800° C.

2. The *lowest* temperatures at which bending has been observed are:

For an American carbon rod 1800° C.
For a German carbon rod 1900° C.
For a graphite rod 2150° C.

3. A rod bent while hot will permanently retain a much greater strain if allowed to cool while under stress. This is especially true of graphite, and below 2700° C. For example, one rod was given a 55° bend at 2630° C. in two minutes; it broke while hot and the pieces were almost

straight (Fig. 1, No. 2). Doubtless the *time* under strain will influence the amount of permanent set also. Up to 2500° C. graphite, though viscous as regards slow changes, is quite elastic for rapid changes and a loaded rod will vibrate freely.

4. In attempting to reproduce some of the other phenomena which LaRosa attributed to fusion, namely to obtain fragments of carbon having rounded outlines, and surfaces having a minutely globular structure, we proceeded in two ways: (*A*) Very regular and rather slow heating, obtained by keeping the current constant (about 400 amperes) while the rod or tube slowly diminished in cross section by burning and sublimation; and (*B*) rapid heating, obtained by suddenly throwing on from 300 to 600 amperes, according to the size of rod. In all cases we tried to remove contained gases by preliminary heating to 2000° C. or more.

Case A.—A one-fourth inch carbon rod would run from three to five minutes in the open air, the temperature gradually rising from $T_t = 2500°$ C.; conditions became unstable with considerable regularity at "black" temperatures of 3080° C. to 3250° C. (estimated at 3300° to 3500° C. "true" temperature), and an arc would be formed. The ends of such rods (or tubes) after arcing never presented any appearance of fusion, except that they were sometimes covered in part with a film or coating having a microscopically globular structure such as was described by LaRosa. Such surfaces were found, for example:

1. In the *cooler* parts of the *inside* of a graphite tube, heated to say $T_t = 3100°$ (in a vacuum) at the hottest part. In this case a layer .1 to .3 mm. thick has been *added* to the inside of the tube, reducing the inside diameter. This layer was considerably *harder* and finer grained than the original graphite.

2. On the *center* of the end of graphite rod used as the negative terminal of an arc, the arc playing around the edge of the end.

3. At various times as spots on the end of rod or tube which had arced, but not where the arc had been.

Case B.—Even with careful preliminary heating we frequently obtained violent explosions, undoubtedly due to rapid generation of carbon vapor in the interior of the rod. A further interesting result of this rapid generation of carbon vapor is the very pronounced swelling of carbon rods (less marked with graphite) which occurred with rapid heating (Fig. 1, No. 4). Though the temperature of the surface did not rise above 3000 to 3200° C. (true temperature) the interior was undoubtedly much hotter. A section of such an expanded rod is shown in Fig. 2, No. 1; the center is full of holes and crumbles at the touch, but has no appearance of fusion. A very peculiar effect due to the flow of carbon vapor from the interior of the rod is shown in Fig. 2, No. 2. This nodulated surface presents every appearance of having been fused; yet it is to be noted that such appearances occur only on the outside (and hence cooler) part of the rod; they are more marked with large than with small rods (greater temperature difference between outside and inside); they occur at temperatures several hundred degrees lower than those at which, with slow heating, it has been found possible for a solid carbon or graphite rod to exist. (See above.)

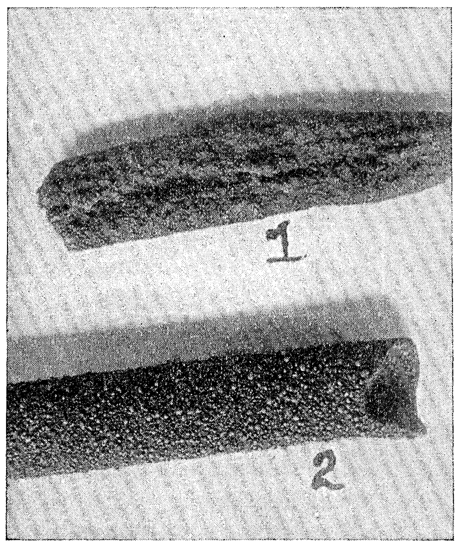

Fig. 2.

Therefore, while the surface appearances described at first sight suggest fusion, we are convinced that they are due in all our cases to condensation of carbon in the relatively cooler regions. The maximum temperature which can be obtained by electrically heating carbon is fixed by the sublimation point at the pressure used. Further increase of energy input after this point is reached simply goes into the energy of sublimination of the carbon. In a vacuum graphite tube furnace at a few millimeters pressure we have obtained in this laboratory a maximum (true) temperature of about 3100° C.; while with a carbon rod in air at 1 atm. pressure we obtained as high as 3500° C. With the same pyrometer a 250 ampere arc gave $T_b = 3500°$ C., or $T_t = 3800°$. The difference between the arc temperature and the highest observed with a rod is undoubtedly the difference between the surface and interior temperature of the rod—the rod breaking down when the *inside* temperature reaches that of the arc.

Conclusion.

In view of the above experiments it seems reasonable to conclude that the bending of carbon and graphite at high temperatures cannot of itself be taken as evidence of incipient fusion—but rather as evidence of a gradually increasing plasticity; and while we cannot be sure that the peculiar surface effects observed by us and ascribed to condensation of carbon vapor are the same as observed by LaRosa, still their strong resemblance would lead us to suggest that probably the phenomena described by him were due to condensation and not to fusion.

University of Wisconsin,
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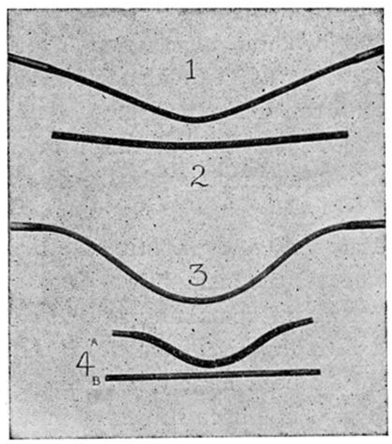

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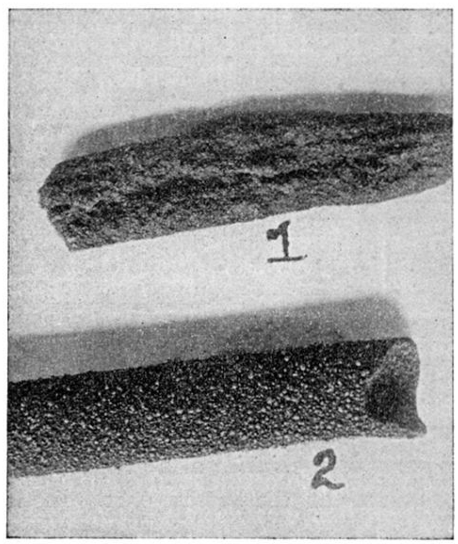

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