CHAPTER I.

THE APPEARANCE OF THE ARC.

SINCE the discovery of the electric arc early in the present century, Nature has been subjected to a series of questions with the object of extracting from her a statement of the mysterious laws that govern it. These questions—which we call experiments—she has, so far, answered but sparingly. They have been repeated again and again, but, even when replies have been vouchsafed, they have been couched in such ambiguous terms that one experimenter has interpreted them in one way, and another in another, and we are still far from having a clear understanding of the laws of the arc.

A certain amount of knowledge has, however, been gained, and it is proposed in the present work to deal with some of the facts that have been acquired concerning direct-current arcs, maintained between carbon rods, the arc being not longer than the diameter of the positive carbon, and the potential difference between the rods being not greater than, say, 100 volts. It is proposed, in fact, to deal only with such direct-current arcs as are used in the lighting of our streets, and to leave on one side alternate-current arcs, very long arcs maintained with a large potential difference between the carbons, and arcs maintained between metals.

The arc is so bright that, if looked at with the naked eye, it appears to be simply a dazzlingly bright spot with needle-like rays diverging from it in all directions, but by projecting its image on to a screen its real shape and colour may be easily observed—if the image is magnified, so much the better.

In arcs maintained between vertical carbon rods, with the positive carbon uppermost, both shape and colour vary according to the length of the arc and the current flowing, but certain characteristics are common to all. In all, the end of the positive carbon is more or less pointed, with a depression at the tip called the crater. This depression is shallower, the longer the arc, and is practically non-existent with arcs of lengths approaching the diameter of the positive carbon.

The end of the negative carbon is also pointed, but instead of a depression it often has a sort of little hillock on the tip. The tips of both carbons are white hot, and in the space between them there is a faint purple light, outlined by a deep shadow.

At a very early stage in the experiments made by the students of the Central Technical College, under Prof. Ayrton's direction, it was found that altering either the current or the length of the arc caused a change in the shapes of the carbons and visible arc, which in some cases was very considerable. It was therefore thought advisable to obtain a record of these changes under all circumstances, and diagrams of the carbons and arc were taken, when the potential difference had acquired its steady value, for all the currents and lengths of arc observed.

The diagrams were obtained by placing a piece of squared paper over the screen on which the enlarged image of the arc was projected, and drawing the complete outlines of the carbons and image. The carbons are always easy enough to draw for they are very definite, but the exact curve which outlines the purple image of the arc is much more difficult to obtain, for this image melts off very gradually into the surrounding darkness.

Fig. 1 is a reproduction of one of the diagrams half of the original size, and since the original diagram enlarged the carbons *ten* times, this reproduction shows them *five* times full size It may be observed that there is a white-hot crater at the end of the positive carbon, and a white-hot tip to the negative, and that the area of the crater in the positive is much larger than the area of the white-hot tip of the negative. That this glowing tip of the negative carbon gives out a fair amount of light may be easily seen by observing the beam of light from an arc after it has passed through a lens. This beam divides itself into two distinct parts, separated by a dark space, so that it looks like two beams, one coming from the crater of the positive, the other from the bright spot on the negative carbon. If a piece of paper be placed in the dark space between the two beams, it will have a faint violet

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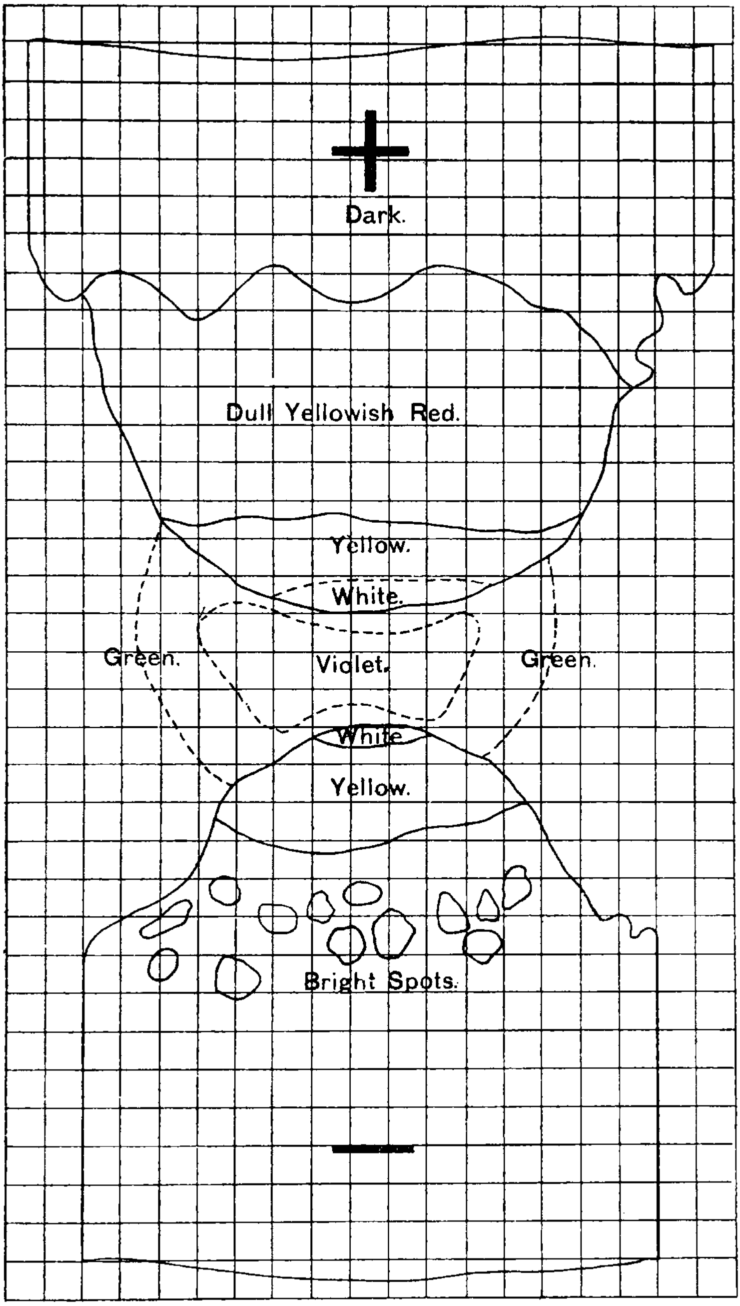

FIG. 1.—Image of Carbons and Arc 5 times full size. Current, 10 amperes. Length of Arc, 3mm. P.D. steady at 46·5 volts.

light on it, but this light is evidently not sufficient to make the dust particles in the air visible.

The area of the bright spot on the tip of the negative carbon increases with the current, but at a much slower rate than the area of the crater in the positive, so that the ratio of the area of the crater to the area of the negative bright spot increases rapidly as the current is increased, with silent arcs.

The part marked "bright spots" on the negative carbon represents a circlet of seething balls, which, whatever they may be, always appear at the junction of the light and dark parts of the negative carbon. Above them, as far as the line which is marked "yellow," the carbon presents a granulated appearance, being covered with very small boiling balls, and the whole being of a reddish yellow colour. Then comes the yellow-hot part, marked "yellow," which is quite smooth, and finally the white-hot tip.

The positive carbon has also its smooth yellow-hot part marked "yellow," and its band of granulated darker yellow part above that, and higher still its circlet of seething balls—larger than those on the negative. The outlines of these balls are indicated (Fig. 1) in the highest wavy line, but they cannot generally be seen very distinctly, because no light is thrown on to them to be reflected back again, in the same way as the light from the crater is cast on to the negative carbon.

Looking at the arc itself through smoked glass, instead of at the image, it is seen that these balls are really the frayed ends of an outer crust of the carbon which is peeling off. It is as if the inner part of the carbon, being much hotter than this outer crust, caused it to expand and split, forming a sort of fringe hanging down over the inner hotter part from which it has broken away. Between this crust—which crumbles at a touch when cold—and the body of the carbon there is a space of from $\frac{1}{2}$mm. to 1mm. to the height of 5mm. or more, from which when the arc is burning sparks fly out, drop down to the edge of the crust, and then fly outwards and upwards, probably carried along by the strong upward draught of the column of hot carbon and air. It is possible that they finally settle on the positive carbon, for after the arc is extinguished this carbon is found to have numerous small particles of carbon on it arranged fairly symmetrically. The tips of the strips of carbon that form the outer crust apparently get burnt by the hot volatile carbon into a semi-globular shape, and they boil and bubble under the action of this heat just as a lump of sugar does when held in a candle flame, and probably the action is really very much the same in both cases.

Fig. 2 is a drawing of a section of a positive carbon with its outer crust, A, showing the way in which this outer crust bulges out and leaves a space between itself and the inner part of the carbon, B.

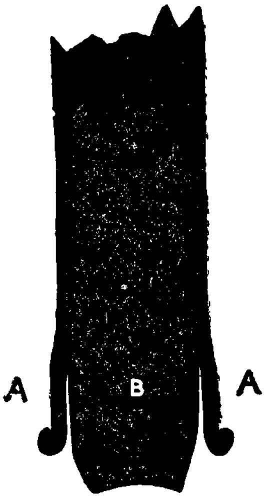

FIG. 2.—Section of Positive Carbon with the Outer Crust curling away from it.

Between the part of the arc marked "violet" in Fig. 1 and that marked "green" there is a dark space, which is scarcely perceptible with small currents and short arcs, but becomes very wide and well marked with large currents and long arcs. The "green" line shows the extreme edge of the luminous part of the arc, or, at least, of that part which is bright enough to show light on the image.

Figs. 3 to 6 show clearly the outlines of the purple and green parts of the arc, and of the shadow between them, under different conditions.

These figures I obtained by tracing the enlarged outlines of the carbons and arc in the way already described; very special attention being given to the outlines of the purple part of the arc, the shadow, and the green outside part. The outlines were then shaded, so as to give as nearly as possible the *values* of the light given out by each part. Thus the most light is given out by the crater of the positive carbon, and by the tip of the negative carbon; therefore these were left white. The shadows between the purple and green parts of the arc are somewhat more abrupt than they really were, but their *shapes* are, I believe, correct. Unless the axes of the two carbons are absolutely in line, the arc is always a little to one side or the other, and that is the reason that the arc in all these four figures is slightly out of the centre; it is almost impossible to get it perfectly central.

In Fig. 4 the outlines of the balls of boiling carbon on the positive as well as on the negative carbon are shown. In Figs. 3 and 5 they could only be seen on the negative carbon, and in Fig. 6 the arc was so long that the screen was not large enough to show the boiling balls on either of the carbons.

The current used for the whole four figures was 20 amperes, the carbons were 18mm. positive and 15mm. negative.

In Fig. 3 the length of arc was 4mm., and the carbons used were both solid. It may be seen that the central purple part of the arc is of the form of an oblate spheroid, broken in upon by the tips of the carbons. Another diagram, made at the same time, of an arc of the same length and with the same current, but with the positive carbon cored, showed a central part of much the same shape, but of smaller area, smaller, in fact, not only in width, but in length, because although the distance between the tip of the negative carbon and the plane through the edge of the crater was in each case 4mm., the central part surrounded a much greater length of the point of the negative with the solid positive carbon than with the cored. The green part of the arc also started much higher up the negative with the cored than with the solid positive carbon, and touched the positive carbon 4mm. from its tip, whereas the green part could be seen at a distance of 14·5mm. up the solid positive carbon (Fig. 3). Thus, the whole visible part of the arc is much larger with a solid than with a cored positive carbon with an arc of 4mm. and a current of 20 amperes, but the general *form* of the arc is very much the same.

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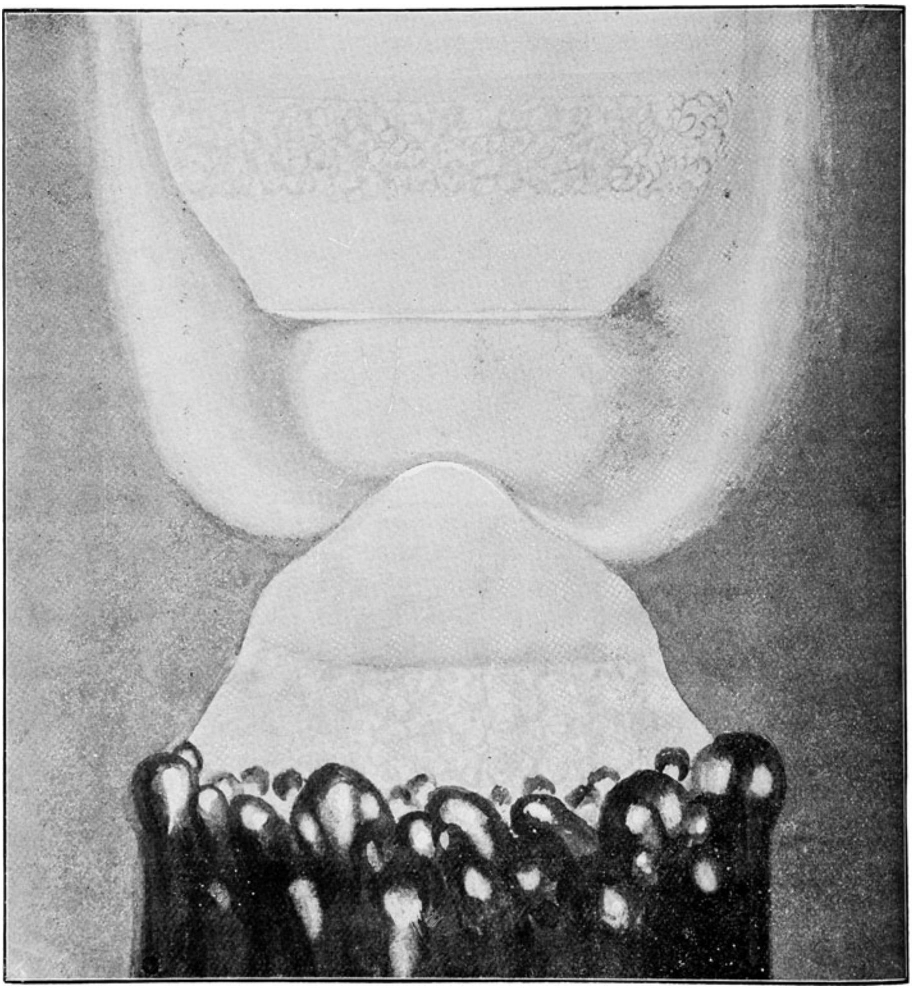

FIG. 3.—Carbons : Positive, 18mm. solid ; Negative, 15mm. solid. Current, 20 amperes.
P.D. between Carbons, 48 volts. Length of Arc, 4mm

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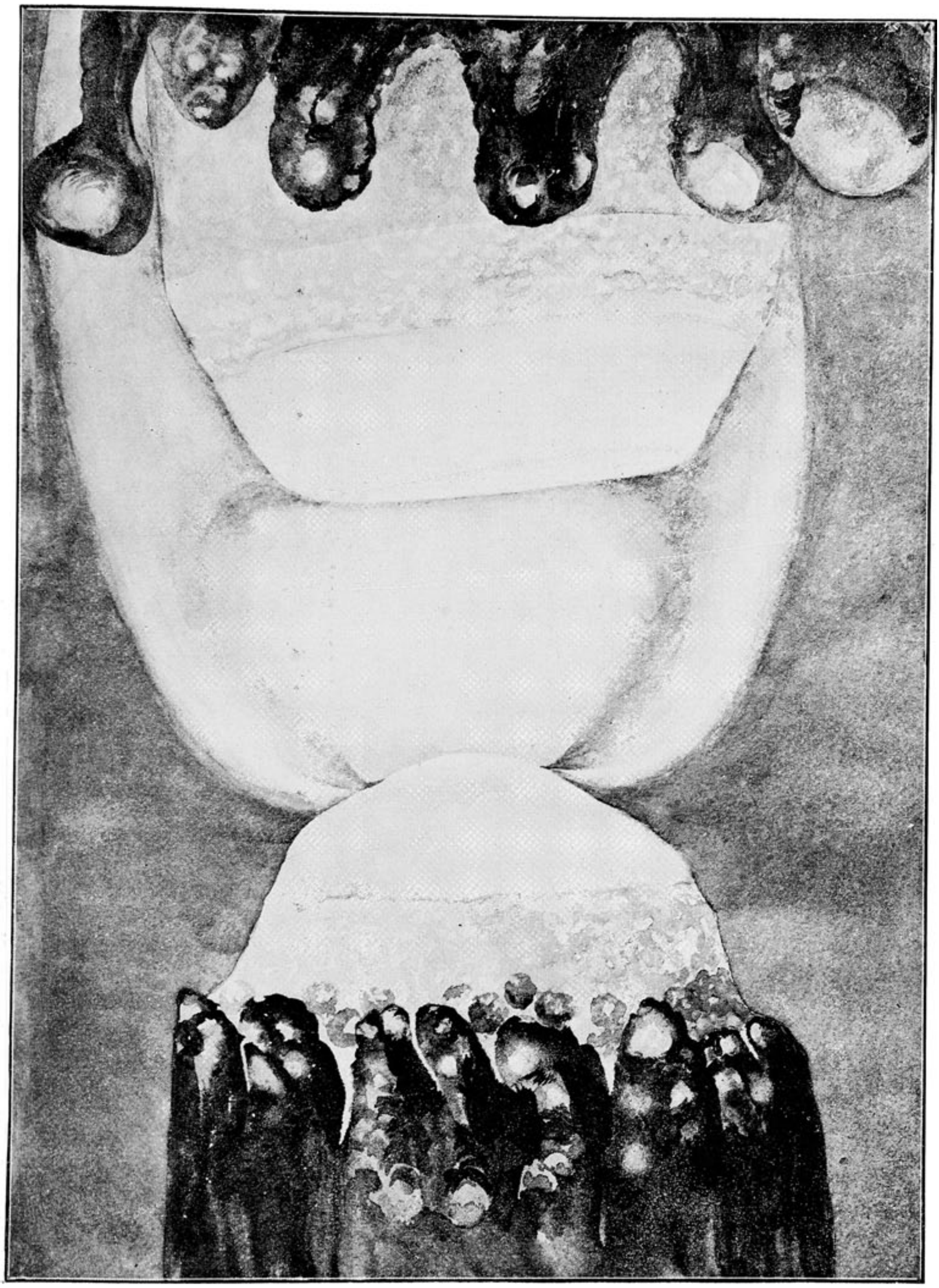

FIG. 4.—Carbons: Positive, 18mm. solid; Negative, 15mm. solid. Current, 20 amperes.
P.D. between Carbons, 56 volts. Length of Arc, 7mm.

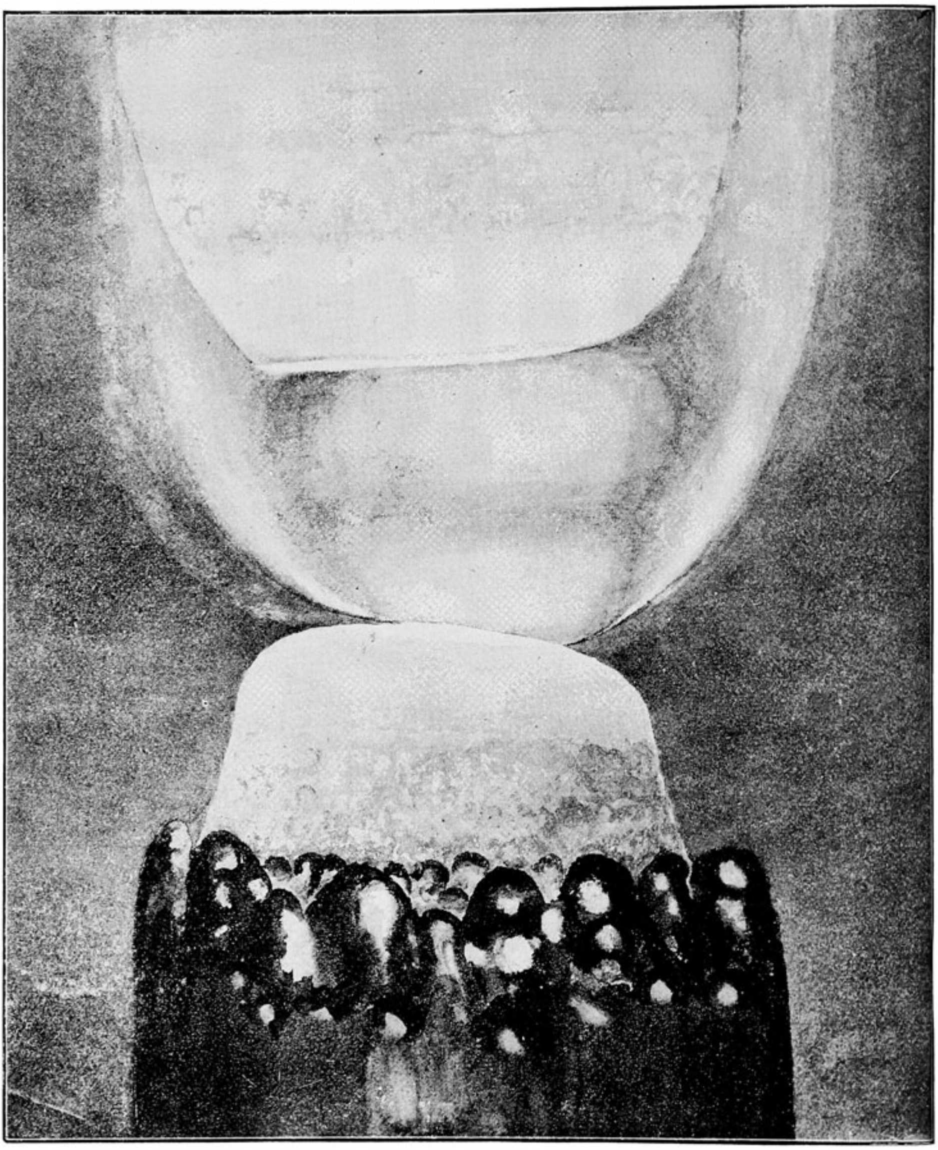

FIG. 5.—Carbons : Positive, 18mm. cored ; Negative, 15mm. solid. Current, 20 amperes. P.D. between Carbons, 51 volts. Length of Arc, 7mm.

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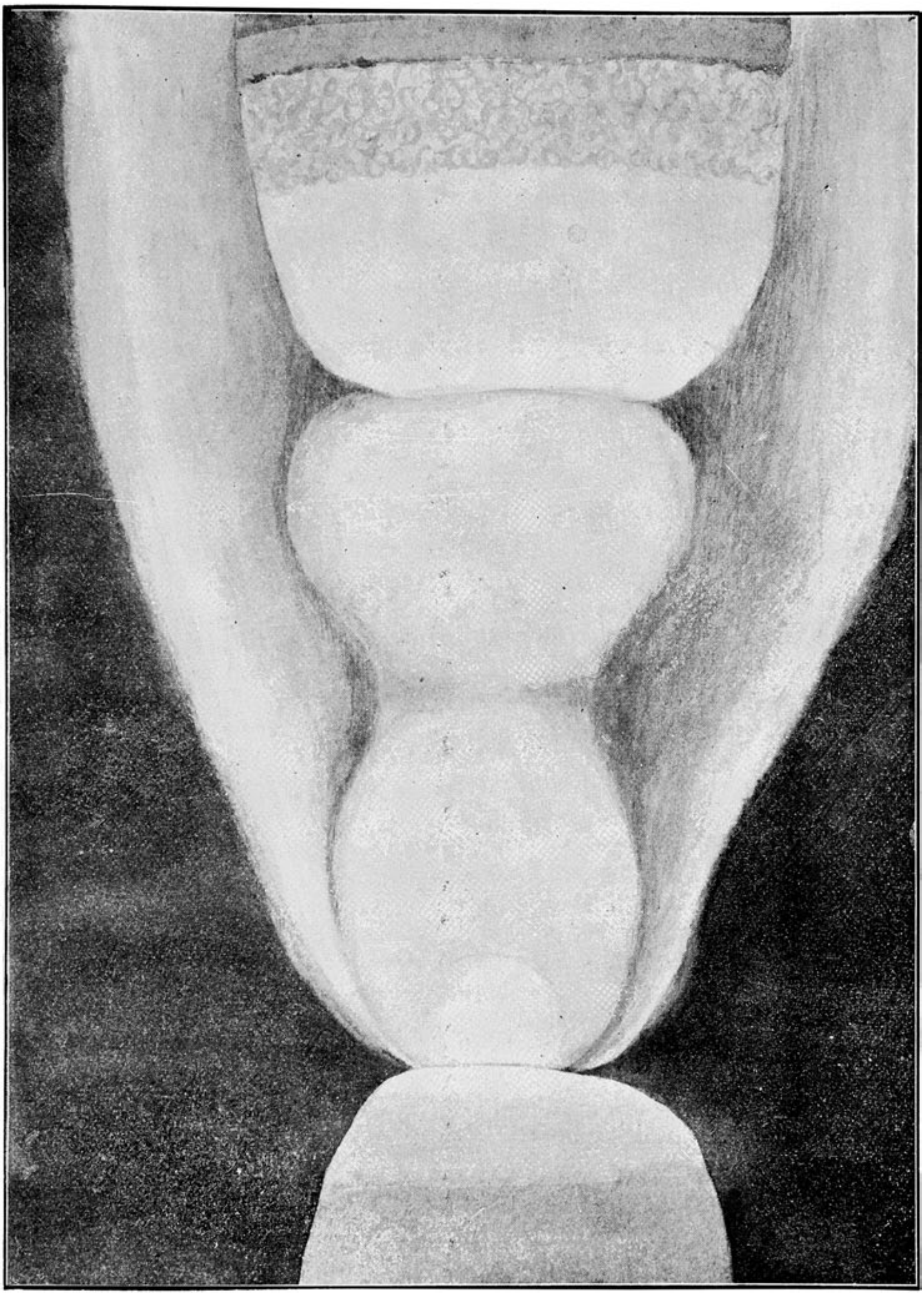

FIG. 6.—Carbons: Positive, 18mm. cored; Negative, 15mm. solid. Current 20 amperes. P.D. between Carbons, 68 volts. Length of Arc, 18mm.

In Figs. 4 and 5 the two arcs are of the same length, 7mm., the current 20 amperes; but for Fig. 4 the positive carbon was solid, and for Fig. 5 it was cored. Here, again, both the central purple part and the green portion surround the negative carbon to a greater distance when the positive carbon is solid than when it is cored; again, also, both the central portion and the whole visible arc are larger with the solid than with the cored positive carbon. But in these two figures the *form* of the central part is also different. With the cored carbon it is gourd-shaped, with the solid, pear-shaped. With the cored carbon the arc has a dark shadow dividing it into two unequal parts, with the solid carbon this shadow is entirely absent. The tip of the positive carbon has a longer, and the tip of the negative a shorter point with the cored than with the solid carbon, which may be due to a lower temperature of the crater in the cored carbon, for, as will be shown later (page 14), greater heat is indicated by a more pointed negative and a less pointed positive carbon.

The balls on the positive carbon in Fig. 4 were not really luminous the whole time I was drawing that figure, but every now and then there was a little hiss caused by some imperfection in the carbon, which lighted them up, and during one of those periods I drew them.

In Fig. 6 the positive carbon was cored, and the arc was 18mm. in length, the current still 20 amperes. In this arc the gourd shape is much accentuated—the central part looks almost like two air balls, the one next the positive carbon placed horizontally, the other placed vertically below it, and touching the negative carbon. The vertical ball has inside it a small ball touching the negative. All three balls were of different shades of purple, the large one near the negative carbon was palest, the small one was darker, and the one near the positive was darkest of all.

The shade of the purple part of the arc was quite different according as solid or cored positive carbons were used, being much bluer with solid than with cored carbons.

I tried to obtain an arc of 18mm. with both carbons solid, in order to compare the two diagrams, but found it impossible to maintain an arc of more than 14mm. with two 18mm. and 15mm. solid carbons. Every time the length of the arc was increased beyond this the arc went out, because, as will be shown later, the E.M.F. of the dynamo was insufficient to maintain a longer arc with a current of 20 amperes flowing when both carbons were uncored. The shape of the 14mm. arc showed no tendency towards the double ball form observable with the cored carbon; it retained the pear shape noticed in Fig. 4. I have, however, found a tendency to assume the double ball form with arcs maintained between solid carbons when the current was very small; but, if the length of the arc is the same in both cases, the current has to be much smaller to produce this form when the positive carbon is solid than when it is cored.

Thus it is clear that when the current is kept constant, altering the length of the arc, alters both its size and shape; and the use of a cored positive carbon, instead of a solid, changes the *size*, the *colour*, and, in long arcs, the *form* of the visible part of the arc.

The diagrams in Figs. 7 to 12 are reproductions of some of those made by Prof. Ayrton's students. They show very accurately the shapes of the ends of the carbons under the given conditions, but, as in Fig. 1, the dotted outlines of the arc must be taken to be only approximately correct. They show, for instance, that, with a given length of arc, the diameter of the visible part of the arc is smaller, the smaller the current, but not with absolute accuracy exactly how much smaller.

These diagrams have been reduced from ten times the full size of the carbons to two-thirds full size, and arranged in order of the sizes of the carbons, the lengths of the arc, and the currents. Figures in the same horizontal row are for the same length of arc with different currents, and figures in the same vertical column are for the same current with different lengths of arc.

We will first examine what is the effect on the shape of the negative carbon of changing (1) the current strength, and (2) the length of the arc; and then we will see what effect these same changes have on the shape of the positive carbon. In all the figures with a short arc, say 0·5mm. (Fig. 7), the negative carbon is quite pointed, even with a small current, and it becomes more and more pointed as the current becomes larger and larger. With a 1mm. arc the negative is less pointed,

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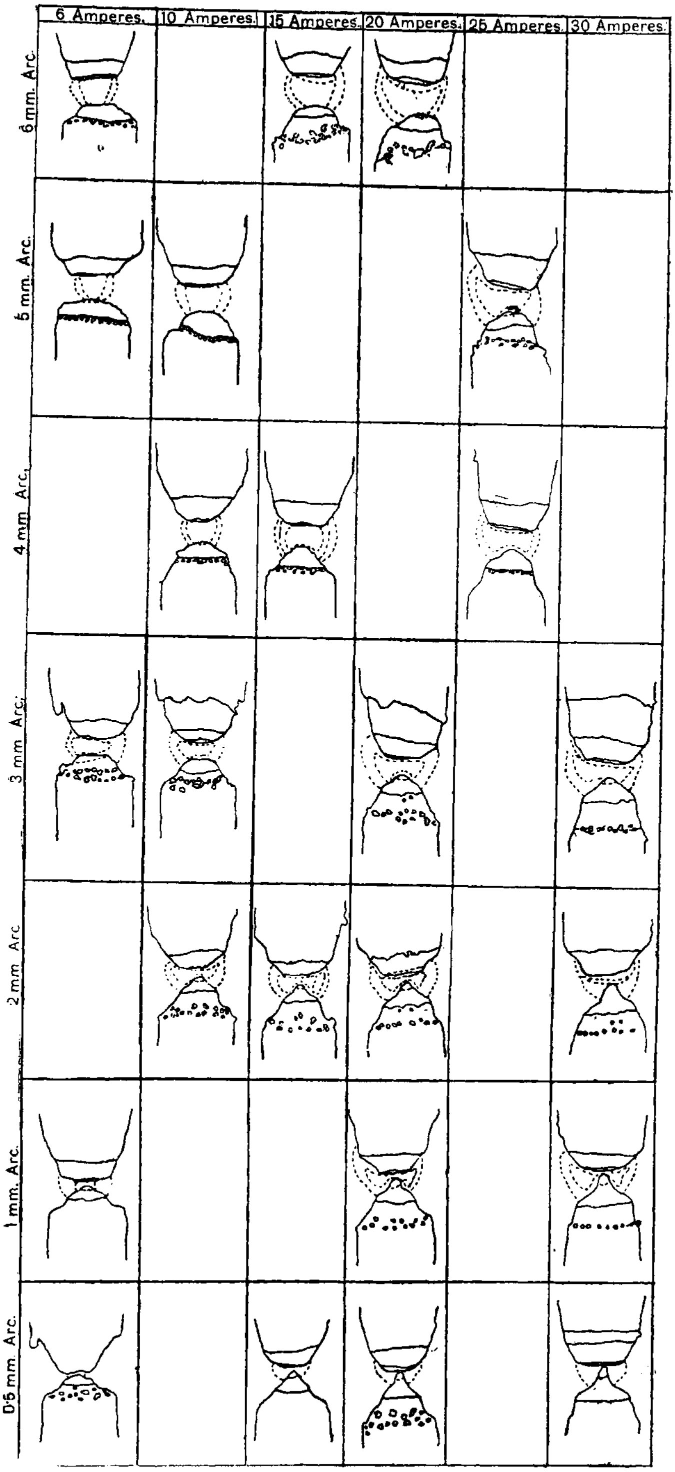

FIG. 7.—Carbons, Positive (upper) 18mm. cored. Negative (lower) 15mm. solid.

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both with small and large currents, than with a 0·5mm. arc, and as the arc gets longer the negative becomes blunter and blunter although in every case it is more pointed with a large current than with a small one for the same length of arc. At last, when the arc is 6mm. long, the negative is quite blunt, even

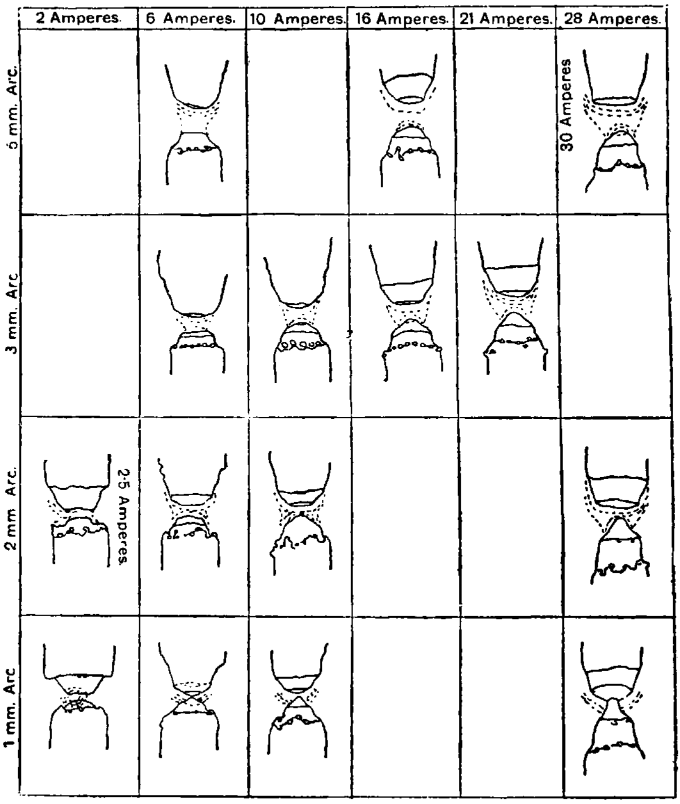

FIG. 8.—Carbons, Positive (upper) 13mm. cored. Negative (lower) 11mm solid.

when a current as great as 20 amperes is flowing. Thus, the tip of the negative is more pointed—

(1) The shorter the arc,
(2) The larger the current.

In order to understand the causes of these phenomena, we must examine the shapes of the negative tips a little more closely.