The PRESIDENT : I have to announce that the Council have to-night appointed Mr. J. L. W. V. Jensen to be Local Honorary Secretary and Treasurer for Denmark in place of the late Mr. P. Christian Dresing, whose death was reported at the last Meeting.

I now call upon Mrs. Ayrton to read her paper on "The Hissing of the Electric Arc."

THE HISSING OF THE ELECTRIC ARC.

By Mrs. AYRTON.

There are three ways in which any change that takes place in the electric arc may manifest itself : (1) by giving out sounds of various kinds or by becoming silent; (2) by changes in its electrical measurements; and (3) by an alteration in the appearance of the crater, the arc, and the carbons. Only two of the many and varied sounds given out by the *direct current open* arc seem to possess much significance—the hum and the hiss—and the causes of these are evidently connected with one another, for the hum never occurs except when the arc is on the point of hissing or has just been hissing, although it is quite possible to make an arc hiss and become silent again without any hum being heard either before or after.

It is proposed, in the present paper, to discuss the arc as it passes from silence to humming and from humming to hissing, but, as the changes that occur when the silent arc begins to hum make themselves perceptible to eye and ear only, and do not sensibly affect the electrical measurements, silent and humming arcs will be included under one head in the portion of the paper dealing with those measurements. It is, however, to the comparatively unexplored region of the direct current *hissing* arc that I desire particularly to direct your attention this evening.

Some of the electrical measurements of the arc burning between two *solid* carbons 11 mm. and 9 mm. in diameter are shown in Fig. 1, in which the curves connect the P.D. between the carbons with the current for several

OPEN ARC.

Solid Carbons

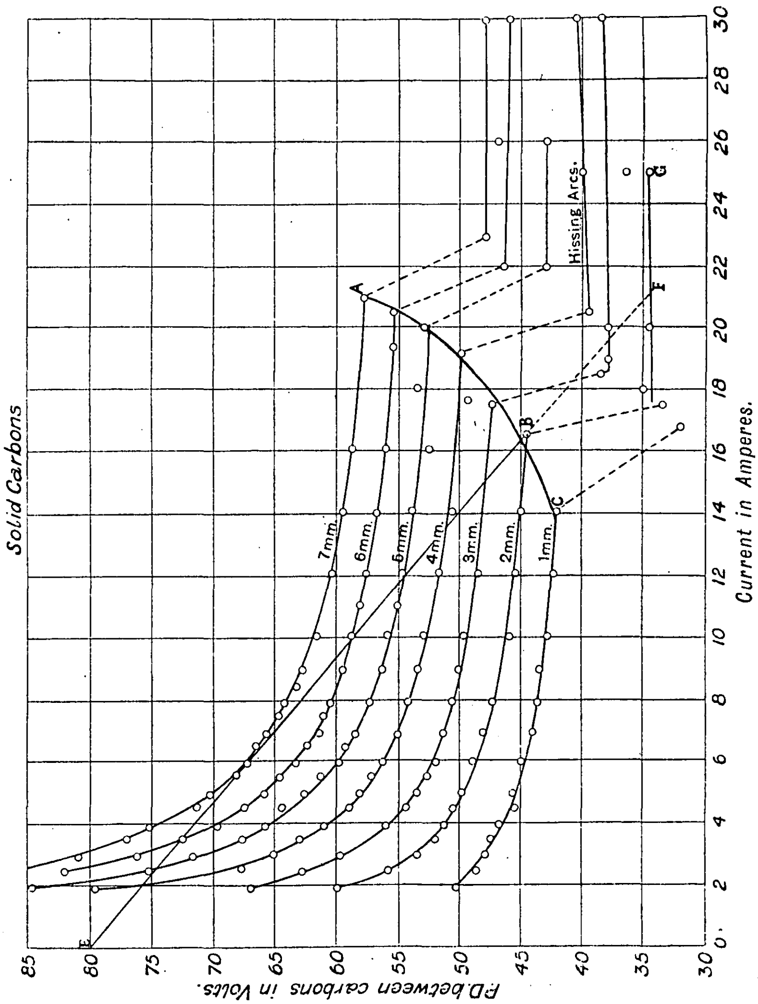

FIG. 1.—Curves connecting P.D. and Current for Constant Length of Arc.

CARBONS.

Positive, 11 mm.; Negative, 9 mm.

constant lengths of arc, both silent and hissing. It is important to bear in mind that before each observation was made the current and length of arc were kept *rigorously* constant for a sufficient length of time for the carbons to take their characteristic shape for that particular current and length of arc, and long enough, therefore, for the P.D. to have become constant also. Such an arc I propose to call a *normal* arc, as contrasted with one arrived at in a haphazard fashion by suddenly giving the current some particular value and the arc some particular length, and making observations without giving the carbons time to acquire their proper forms.

All the lines to the left of the curve A B C represent silent arcs, while immediately to the right of this curve are dotted lines, denoting a period when the arc is in the unstable condition that always divides the silent from the hissing arc; and still further to the right are the lines representing the hissing arc.

As we are only dealing with hissing and humming arcs, and with the silent arcs that are near hissing or humming, we need only discuss that part of Fig. 1 that is to the right of the line representing, say, 12 amperes, for that part includes all such arcs for each of the constant lengths.

An examination of these curves shows that with the carbons used, and with what I have called the *normal* arc, the following results are met with :—

(1) When the length of the arc is constant and the arc is silent, it may be made to hiss by increasing the current sufficiently.

(2) When the current is constant and the arc is silent, *shortening* the arc will make it hiss.

(3) When the arc begins to hiss, the P.D. suddenly falls about 10 volts and the current suddenly rises 2 or 3 amperes.

(4) The largest current that will maintain a *silent* arc is greater the longer the arc.

(5) For the hissing arc, the P.D. is constant for a given length of arc, whatever the current.

It was Niaudet[1] who, in 1881, first observed the fall of about 10 volts in the P.D. between the carbons at the moment that hissing began; and, although, perhaps, there is,

[1] *La Lumière Electrique*, 1881, vol. iii. p. 287.

OPEN ARC.

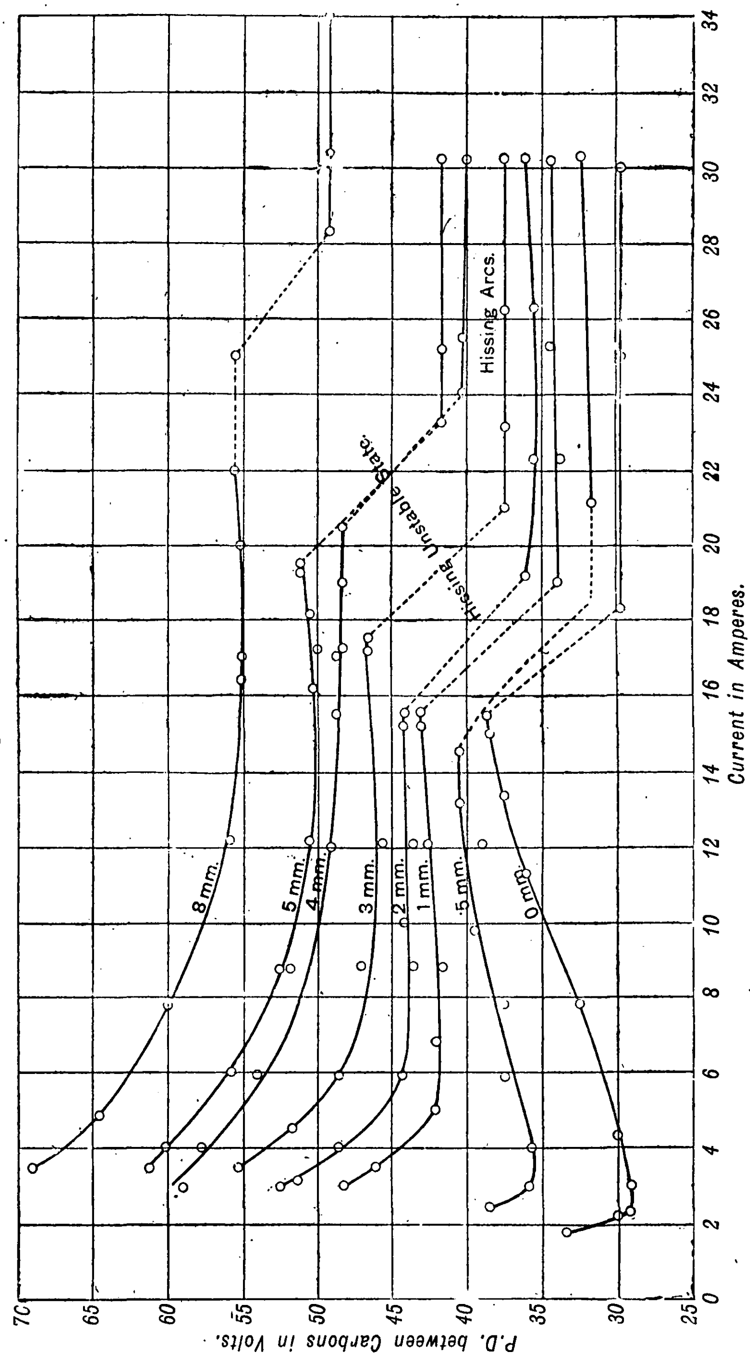

FIG. 2.—Curves connecting P.D. and Current for Constant Lengths of Arc.

CARBONS.

Positive, 9 mm. Cored.; Negative, 8 mm. Solid.

even yet, a lingering notion that it is only when an arc is short that it can hiss, I find that as far back as 1889 Luggin [1] showed that however long an arc might be, it would still hiss were the current increased sufficiently.

At the Congress at Chicago in 1893 Prof. Ayrton [2] first drew attention to the region of instability, or rather, the region of blankness (notice the dotted portion of Figs. 1 and 2), corresponding with the impossibility of maintaining any *normal* arc with a particular range of current for each length. At the same time he pointed out in Fig. 2, shown at Chicago, that whether the P.D. was descending as the current increased for, say, a 4 mm. *silent* arc, or was ascending for, say, a 0·5 mm. *silent* arc, it became quite constant for wide variations of current with a *hissing* arc.

And, lastly, by a comparison of Fig. 2 with Fig. 3, he brought out the fact that the largest current that would flow silently with any given length of arc was increased by using thicker carbons. For the carbons in Fig. 3 have about twice the diameter of those in Fig. 2, and, while the largest silent current for, say, the 2 mm. arc in Fig. 2 is 15·5 amperes, that for the same length of arc in Fig. 3 is about 49 amperes, or more than three times as great.

Returning now to the subject of the dotted lines in Figs. 1, 2, and 3, it is plain that these divide the curves into two perfectly separate parts, governed by different laws. For to the left of the dotted part the lines are all curved, and curved differently according as solid or cored positive carbons are used, showing that with silent arcs the P.D. varies as the current varies, and that the law of variation is different with solid and cored carbons. To the right, on the other hand, the lines are all straight, and more or less parallel to the axis of current, whether the positive carbon is solid or cored, showing that with *hissing* arcs the P.D. is the same for a given length of arc and a given pair of carbons, *whatever* current is flowing, and that this law is true whether the carbons be cored or solid. In fact, some complete and sudden break-down appears to occur when hissing begins, upsetting all the laws that have governed the arc while it

[1] *Wien Sitzungsberichte*, 1889, vol. xcviii. p. 1192.
[2] *The Electrician*, 1895, vol. xxxiv. pp. 336–7.

OPEN ARC.

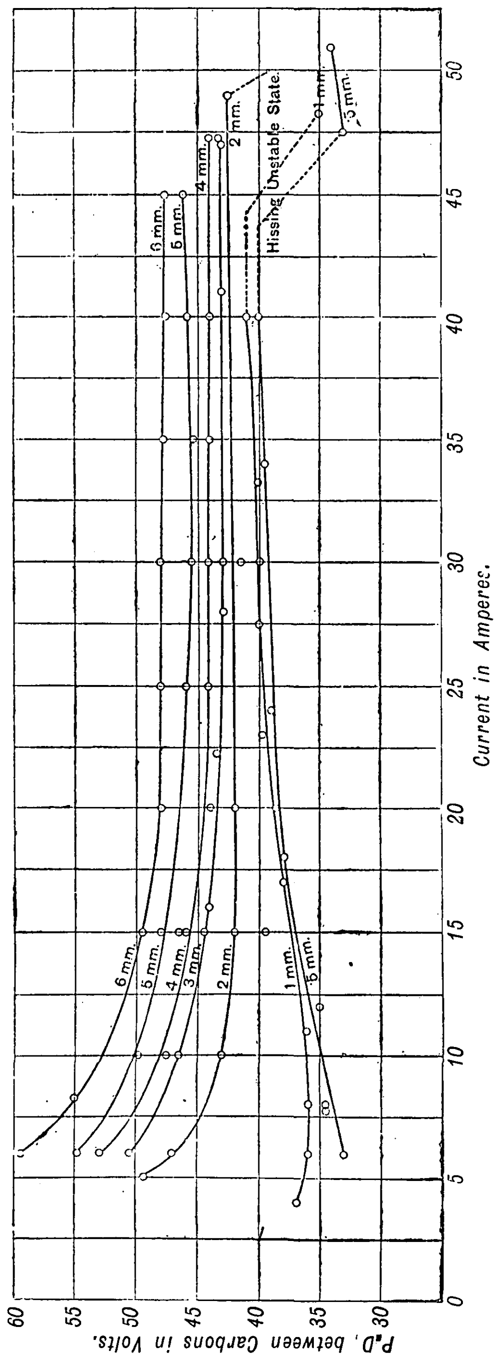

FIG 3.—Curves connecting P.D. and Current for Constant Lengths of Arc.

CARBONS.

Positive, 18 mm. Cored.; Negative, 15 mm. Solid.

was silent, and bringing the behaviour of cored and solid carbons into accord.

Thus, our subject divides itself quite naturally into two distinct portions, the one dealing with the arc when the break-down is imminent, but before it has actually occurred—dealing, that is to say, with the points at which the current is the largest that will flow silently—the *hissing points* as I shall call them; and the other dealing with the arc after the break-down has occurred, and when, therefore, the arc is really hissing.

On examination of Fig. 1, the points of which were obtained experimentally with much care, it is seen that the hissing points lie well on the curve A B C, the equation to which I have shown elsewhere [1] to be

$$V=40{\cdot}05+\frac{2{\cdot}91A-29{\cdot}02}{10{\cdot}54-0{\cdot}416A} \quad \ldots\ldots\ldots\ldots \quad (1)$$

where V is the P.D. between the carbons in volts, and A is the largest silent current in amperes. Or, expressing the P.D. in terms of l, the length of the arc in millimetres, instead of in terms of the current at the hissing points, we have

$$V=40{\cdot}05+2{\cdot}49\,l \quad \ldots\ldots\ldots\ldots \quad (2)$$

which shows that at the hissing points any given increase in the length of the arc causes an increase in the P.D. between the carbons that is simply proportional to the increase of length. That is to say, for every millimetre that is added to the length of the arc, 2·49 volts is added to the P.D. between the carbons at the hissing point.

From the above two equations I deduced the third, viz:

$$l=\frac{1{\cdot}17A-11{\cdot}66}{10{\cdot}54-0{\cdot}416A} \quad \ldots\ldots\ldots\ldots \quad (3)$$

and pointed out that, since l was infinite when

$$10{\cdot}54-0{\cdot}416A=0, \text{ or when } A=25{\cdot}3 \text{ amperes},$$

no current greater than 25·3 amperes could maintain a normal *silent* arc, however long it might be made with the particular carbons used. Hence we may gather that *for each pair of carbons the current that will sustain a normal silent arc has a maximum value, and that any current greater than this will make the arc hiss, however long it may be.*

[1] *The Electrician*, 1896, vol. xxxvi. p. 541.

To turn, now, to the arc when hissing has actually begun. It has already been shown that *when the arc is hissing, the P.D. between the carbons is constant for any given length of arc, and is therefore independent of the current;* but no law has yet been given connecting the P.D. between the carbons with the length of the arc when hissing. This can now be found from Fig. 1, by plotting the mean P.D. between the carbons for each length of arc when it was hissing, with the corresponding lengths of arc. In this way we get a straight line, the equation to which is

$$V = 29{\cdot}25 + 2{\cdot}75\, l \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \qquad (4)$$

How far equation (4) really sums up the facts may be seen from Table I., which gives the mean value of the observed P.D. between the carbons for each length of hissing arc, the P.D. calculated from equation (4), and the difference between the two.

TABLE I.—HISSING ARCS.

MEAN P.D. BETWEEN CARBONS FOR DIFFERENT LENGTHS OF ARC COMPARED WITH SAME P.D. CALCULATED FROM EQUATION (4).

Carbons: Positive, 11 mm. Solid; Negative, 9 mm. Solid.

Length of Arc in Millimetres.	Mean P.D. between Carbons in Volts.	P.D. calculated from Equation (4).	Difference in Volts.
1	32	32·0	0
2	34·4	34·75	−0·35
3	37·8	37·5	+0·3
4	40·0	40·25	−0·25
5	43·0	43·0	0
6	46·5	45·75	+0·75
7	48·0	48·5	−0·5

Equation (4) shows that, *with the hissing as with the silent arc, a straight line law connects the P.D. between the carbons with the length of the arc.*

There is, however, this vast difference between the law for silent and that for hissing arcs, viz., that, for silent arcs, the law only holds for constant currents or for the currents at the hissing points, whereas for hissing arcs it holds *whatever the current may be.* Thus, while for silent arcs the constants which correspond with the terms 29·25 and 2·75 in equation (4) are constant only for each separate current, and change when the current changes, with *hissing* arcs they remain the same *whatever* the value of the current may be. For instance, the equation equivalent to equation (4) for a normal silent arc with a current of 4 amperes is

$$V = 41{\cdot}79 + 4{\cdot}71\, l,$$

and with a current of 12 amperes it is

$$V = 39{\cdot}85 + 2{\cdot}95\, l;$$

but with the hissing arc the equation is

$$V = 29{\cdot}25 + 2{\cdot}75\, l,$$

whether the current be one of 20 amperes or of 50, *and whether the arc be normal or not.*

This brings me to the reason for the great importance of distinguishing between arcs that are normal and those that are not. We have seen that, with normal arcs of any given length, hissing only starts when all the silent arcs have been used up, as it were; that is to say, when the current is *greater* than it can be with any silent arc of the same length. But with a *non*-normal arc of 2 mm. I have been able to produce hissing with a current of 11 amperes, and to have a silent arc burning with a current of 28 amperes, the same carbons being used in each case. This apparent anomaly will be fully explained later, when we go into the causes that produce hissing.

We are now in a position to find the law that connects the length of the arc with the change that takes place in the P.D. between the carbons when hissing begins. For, if we call V the P.D. between the carbons at the *hissing point*, with any given length of arc l, and V′ the same P.D. when the same length of arc is hissing, then from equations (2) and (4) we get—

$$V - V' = 10{\cdot}8 - 0{\cdot}26\, l \ldots\ldots\ldots\ldots \quad (5)$$

which shows that *the longer the arc the less does the P.D. between the carbons diminish when it changes from silence to hissing.*

In 1889, Luggin[1] found, by measuring the fall of potential between each carbon and the arc, that the principal part of the diminution of P.D. caused by hissing took place at the junction of the positive carbon and the arc. About three years ago, not then having come across any account of Luggin's experiments, I made some of the same sort myself and obtained the same result. I used two solid Apostle carbons 11 mm. and 9 mm. in diameter, and the third carbon for placing in the arc was 3 mm. in diameter. This last was somewhat thick, but it burnt well to a point in the arc, and thinner carbons burnt away too rapidly with the current I used—25 amperes—to give good measurements. The P.D. between the positive carbon and the arc was found by placing the third carbon in the arc as close as possible to the positive carbon, and measuring the P.D. between the two with a very high resistance voltmeter. This was easily done when the arc was hissing, but was impossible when the largest silent current was flowing, for then the mere insertion of the third carbon was sufficient to make the arc hiss. Accordingly the P.D. between the positive carbon and the arc when the largest *silent* current was flowing has had to be calculated from the formula I gave at the meeting of the British Association[2] last year for calculating that P.D. with *any* silent current, viz.:

$$V = 31{\cdot}28 + \frac{9 + 3{\cdot}1\,l}{A}$$

In Table II. two sets of currents are dealt with, viz., the largest silent current for various lengths of arc, and a hissing current of 25 amperes; and, for each of these sets of currents and lengths of arc, two P.D.'s are given, viz., the P.D. between the main carbons, and the P.D. between the positive carbon and the arc itself.

[1] *Wien Sitzungsberichte,* 1889, vol. xcviii. p. 1192.
[2] *Report of the British Association,* 1898, p. 805.

TABLE II.

P.D. BETWEEN CARBONS, AND P.D. BETWEEN POSITIVE CARBON AND ARC WITH LARGEST SILENT CURRENT AND WITH HISSING CURRENT OF 25 AMPERES.

Carbons : Positive, 11 mm. Solid ; Negative, 9 mm. Solid.

Length of Arc in Millimetres.	Largest Silent Current.		Hissing Current of 25 Amperes.	
	P.D. between Carbons in Volts.	P.D. between Positive Carbon and Arc in Volts (calculated).	P.D. between Carbons in Volts.	P.D. between Positive Carbon and Arc in Volts.
(1)	(2)	(3)	(4)	(5)
1	42·2	32·1	32·1	24·4
2	44·5	32·2	34·6	25·2
3	47·5	32·3	37·0	25·7
4	49·4	32·4	40·5	25·7
5	53·0	32·5	43·9	27·9
6	55·5	32·6	45·9	27·2

Now, in order to compare the change in the P.D. between the main carbons caused by hissing, with the corresponding change in the P.D. between the positive carbon and the arc, we must subtract column (4) of Table II. from column (2), and column (5) from column (3), and compare the differences. These differences are given in Table III.

TABLE III.

DIMINUTION OF P.D. BETWEEN CARBONS DUE TO HISSING COMPARED WITH CORRESPONDING DIMINUTION OF P.D. BETWEEN POSITIVE CARBON AND ARC.

Carbons: Positive, 11 mm. Solid; Negative, 9 mm. Solid.

Length of Arc in Millimetres. (1)	Diminution of P.D. between Carbons due to Hissing. (2)	Diminution of P.D. between Positive Carbon and Arc due to Hissing. (3)
1	10·1	7·7
2	9·9	7·0
3	10·5	6·6
4	8·9	6·7
5	9·1	4·6
6	9·6	5·4

Thus, for the lengths of arc dealt with, hissing causes a mean fall of about 9·7 volts in the total P.D. between the main carbons, and a mean fall of about 6·3 volts in the P.D. between the positive carbon and the arc. Hence of the whole diminution of the P.D. between the carbons caused by hissing, about two-thirds takes place at the junction of the positive carbon and the arc.

Further, my experiments showed that very little of the remainder of the diminution, if any, was due to a fall of the P.D. between the arc and the negative carbon; therefore this remaining diminution must be attributed to a lowering of the resistance of the arc itself. We may sum up these results as follows:—

Of the total diminution of the P.D. between the carbons caused by hissing, about two-thirds takes place at the junction of the positive carbon and the arc, and the remaining third seems to be due to a lowering of the resistance of the arc itself.

From Fig. 1 it might be supposed that, given the length of the arc, the increase of current that abruptly occurs as the arc starts hissing was as definite for that length of arc as the diminution in the P.D. And this, for a long time, I imagined to be the case. But, while trying to find out what law connected the smallest hissing current with the length of the arc, I saw that the value of that current really depended on the circuit *outside* the arc.

For, let E be the E.M.F. in volts of the generator, which we will assume to be constant and independent of the current;

„ r „ resistance in ohms of the whole circuit *outside* the arc;

„ l „ length of the arc in millimetres;

„ A „ largest silent current in amperes;

„ V „ corresponding P.D. between the carbons in volts;

„ A′ „ smallest hissing current in amperes;

„ V′ „ corresponding P.D. in volts,

$$\text{then } E = V + Ar$$
$$\text{and } E = V' + A'r,$$

$$\therefore \frac{A' - A}{V - V'} = \frac{1}{r}$$

that is, the sudden increase of current when hissing begins equals the product of the sudden diminution of the P.D. into the conductance of the circuit outside the arc.

$$\text{Again, } \frac{A'}{A} = \frac{E - V'}{E - V},$$

$$\text{or } A' = \frac{E - V'}{E - V} A,$$

But for a given hissing point, for example, B (Fig. 1), V, V′, and A are all constants; therefore for such a point A′ depends simply on E.

In fact, for a fixed point B and a fixed line F G, the position of the point F merely depends on the slope we give to the line E B F; that is, on the point on the axis of P.D. we select for E. And a consideration of the figure shows that the distance between this point E and the axis of current measures E, the E.M.F. of the dynamo. Consequently it now appears that the dotted lines in the unstable region constitute records of the particular E.M.F.'s the dynamo was made to give on the various days when the experiments were made with the different lengths of arc, several years ago.

Hence, when the largest silent current changes to the smallest hissing current for the same length of arc, the value of that smallest hissing current depends on the E.M.F. of the generator only.

Thus, it is possible, by choosing suitable E.M.F.'s, to make the sudden smallest hissing current have any value greater than that of the largest silent current for the same length of arc. It is evident from Fig. 1 that the smaller the E.M.F. of the generator, the larger will be the value of the smallest hissing current, for the lower down will E be on the axis of P.D., and therefore the farther will the point F be along the line F G. This explains a circumstance that puzzled me greatly when it happened, but which is now perfectly comprehensible. Some years ago, I was using accumulators to maintain an arc, and employing as small a number of cells as possible. I was able to have quite a moderate current as long as the arc was silent, but as soon as it began to hiss, the current rushed up to some huge value which would inevitably have ruined the cells, if I had not had a cut-out arranged to break the circuit. Why the first hissing current should be so much greater than I was accustomed to find it with the dynamos I ordinarily used, I could not imagine, but the reason is now perfectly obvious. The hissing current was so great simply because the E.M.F. of the cells was so small, and, had it been possible to maintain a silent arc without any resistance in the outside circuit except that of the cells, which is what I was trying to accomplish, I might, except for the cut-out coming into operation, have had practically an infinite current when the arc began to hiss.

We now pass from the consideration of the electrical measurements of the arc to the appearance of the crater, arc, and carbons.

Every alteration of the current and of the distance between the carbons naturally produces a corresponding modification of all parts of the arc, but, until the value of the current attains a certain magnitude, which depends only on the length of the arc with a given pair of carbons, this change is one of degree merely, and not of character. A greater current simply produces a larger crater, a larger arc, and longer points to the carbons. When the special current is reached, however, a change which is no longer merely one of degree, takes place in the crater. Instead of presenting a uniformly bright surface to the eye, this becomes partly covered with what appear to be alternately bright and dark bands in one or more sets of concentric circles, moving round different centres in opposite directions. The directions of rotation and the entire positions of the images change continually, and the motion grows faster and faster as the current is increased.

It is impossible that these figures, which do not move too fast to be clearly seen by the eye in an image of the arc magnified only ten times, should have escaped the observation of all those who have made a study of the arc, and yet, after a careful search, I can find no mention of them anywhere.

When the current is so much increased that the motion becomes too fast for the eye to detect, the arc begins to hum, and then, as Mr. Trotter[1] first showed in 1894, it rotates at the rate of from 50 to 450 revolutions per second. These rapid revolutions, which the unaided eye is incapable of observing, he discovered by the use of a disc having alternate arms and spaces, and kept in rapid rotation; but, in his account of his observations, he makes no reference to the relatively slow rotations which *precede* the hum. In fact, the rotations observed by Mr. Trotter appear to begin just where those I have been describing become too quick for the eye to see unaided, and end just as the arc begins to hiss, for he mentions that at 450 revolutions per second the arc breaks into a hiss.

As soon as hissing begins the whole appearance of the crater changes again; a sort of cloud seems to draw in round a part of it, moving from the outer edge inwards, and varying continually in shape and position. Sometimes but one bright spot is left, sometimes several, but always the surface is divided into bright and dull parts, giving it a mottled appearance, as is slightly indicated in (*b*) Fig. 4. If, then, the current be diminished, so that the arc becomes silent again, the whole surface of the crater grows dark

[1] *Proc. Roy. Soc.*, 1894, vol. lvi. p. 262.

SILENT. HISSING.

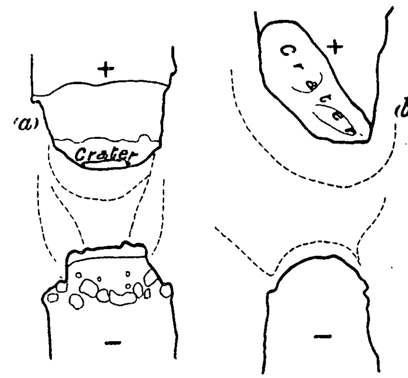

FIG. 4.

CARBONS.

Positive, 9 mm. Cored ; Negative, 8 mm. Solid.

LENGTH OF ARC.

(*a*) 5 mm., (*b*) 8 mm.

CURRENT.

(*a*) 3·5 amperes, (*b*) 34 amperes.

HISSING.

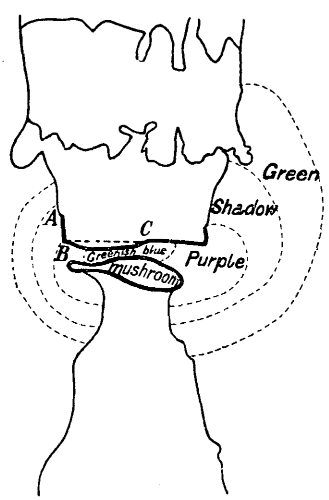

FIG. 5.

CARBONS.

Positive, 11 mm. Solid ; Negative, 9 mm. Solid.

LENGTH OF ARC, 1·5 mm. CURRENT, 28·5 amperes.

for an instant, then brightens in spots, and finally becomes bright again all over.

The vaporous arc itself undergoes fewer modifications;

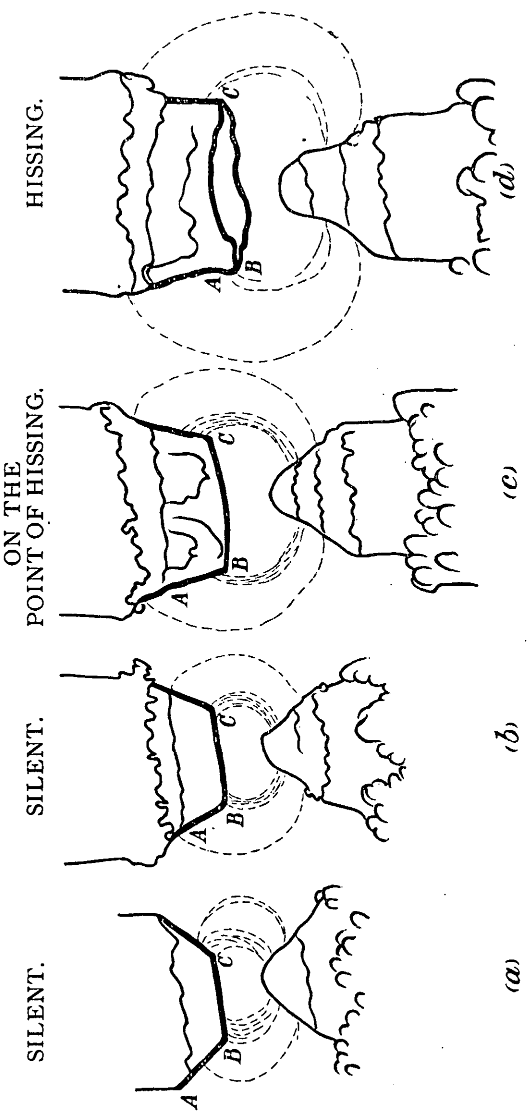

FIG. 6.

CARBONS.

Positive, 11 mm. Solid; Negative 9 mm. Solid.

LENGTH OF ARC, 2 mm.

CURRENT.

(*a*) 6 amperes, (*b*) 12 amperes, (*c*) 20 amperes, (*d*) 30 amperes.

it preserves the ordinary characteristics of the silent arc while dancing circles hold possession of the crater, but, when humming begins, a green light is seen to issue from the crater, and with hissing this becomes enlarged and intensified, till the whole centre of the purple core is occupied by a brilliant greenish-blue light, as is indicated in Fig. 5. The *shape* of the arc now alters also. While it is silent or humming, no great difference can be observed in its form. With solid carbons it is rounded or pear-shaped according to its length, and has an appearance of great stability. But as soon as hissing occurs the arc seems to suddenly dart out from between the carbons and to become flattened out, as if under the influence of a centrifugal force acting at right angles to the common axis of the two carbons. In Fig. 5 this flattened appearance is well marked, as it is also in (*d*) Fig. 6; and indeed these figures show that every part of the vaporous arc itself is involved in this flattening—the purple core, the shadow round it, and the green aureole—as if they were all revolving with great rapidity round a common axis. And what more likely than that this should be the case, since, as has already been mentioned, the arc is revolving at the rate of 450 revolutions per second *at the moment that it starts hissing?*

As regards the carbons themselves, the only important modification of the *negative* carbon that appears to be due to hissing is the formation of the well-known "mushroom" at the end of that carbon with a *short* hissing arc. This mushroom, of which a good example is seen in Fig. 5, is well named, not only because of its shape, but also because of the rapidity of its growth, which is so great that, while it is forming, the carbons often have to be *separated*, instead of being *brought together*, to keep the length of the arc constant.

And now we come to the most important of all the changes that take place when the arc begins to hiss, viz.: the alteration in the shape of the *positive* carbon.

During the course of his 1889 experiments, Luggin[1] observed that the arc hissed when the crater filled the whole of the end of the positive carbon. He was thus the first to call attention to the fact that there was a direct connection between hissing and the relation between the area of the crater and the cross-section of the tip of the positive carbon. My own observations in 1893 led to a conclusion somewhat

[1] *Wien Sitzungsberichte,* 1889, vol. xcviii. p. 1192.

similar to Luggin's, but yet differing in an important particular. It seemed to me that with hissing arcs the crater always *more* than covered the end of the positive carbon—that it overflowed, as it were, along the side. How far this is true will be seen from an examination of Figs. 4, 5, 6, and 7, which show the shaping of the carbons under various conditions with silent and hissing arcs. These figures have all been made from tracings of the images of actual normal arcs, burning between carbons of various sizes. For Fig. 4 the diameters of the carbons were the same, but the currents and lengths of arc were different. Fig. 5 is the image of a

SILENT. HISSING.

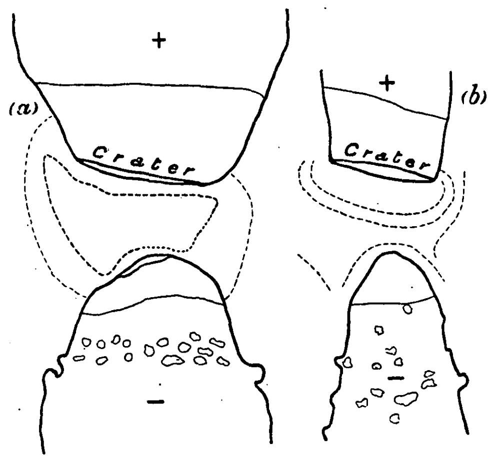

FIG. 7.

CARBONS.

(*a*) Positive, 18 mm. Cored. Negative, 15 mm. Solid.
(*b*) Positive, 9 mm. Cored. Negative, 8 mm. Solid.

LENGTH OF ARC, 5 mm. CURRENT, 25 amperes.

short hissing arc. For Fig. 6 the positive carbons were all of the same size, and the arcs of the same length, but the current had four different values, while for Fig. 7 the current and the length of the arc were the same for both (*a*) and (*b*), but the diameter of one of the positive carbons was twice that of the other. The figures were carefully chosen with special reference to the shaping of the positive carbons. For with normal arcs the shape of the end of a positive carbon, even taken quite apart from that of the negative carbon and of the vaporous arc itself, is capable of revealing almost the whole of the conditions under which the arc was burning when it was formed. It is possible, for instance, with a normal arc, to tell, from a mere drawing of the outline of the positive carbon and of its crater, whether the arc with which it was formed had been open or enclosed, short or long, silent or hissing, burning with a large or with a small current for the size of the carbon.

Take, for example, Fig. 4, and note the difference in the shape of the positive carbon with a current of 3·5 amperes as in (*a*), and with one of 34 amperes, as in (*b*). In the first case the tip of the positive carbon is rounded, so that the crater lies in its smallest cross-section; in the second, the tip would be practically cylindrical for some distance, but that the crater has burnt away a part of the cylinder, making the tip look as if it had been sheared off obliquely. Comparing now the tips of the positive carbons when the arc is silent and when it is hissing in all the four figures, 4, 5, 6, 7, we find the same difference. With all the silent arcs the tips are more or less rounded, and the crater lies in the smallest cross-section, and consequently is less in area than any but the smallest cross-section. With all the hissing arcs, on the other hand, the tip of the positive carbon is practically cylindrical for a short distance at least, or would be but that it is sheared away by the crater; consequently the area of the crater is *greater* than the smallest cross-section of the tip, or indeed than the cross-section of the tip for some little distance along its length.

We have now arrived at the real, the *crucial*, distinction between a silent and a hissing arc. When the crater occupies the *end* of the positive carbon only, the arc is *silent*; when it not only covers the end, but also extends up the *side*, the arc *hisses*. Hence, the arc must be at the *hissing point* when the smallest increase in the area of the crater will make it begin to cover the *side* of the positive carbon, and this can only be when the tip of that carbon has very nearly the same cross-section for some little distance from its end —in other words, when its sides are nearly vertical.

I shall now proceed to show that the extension of the crater up the side of the positive carbon is not the *effect* but the *cause* of hissing; that, in fact, *hissing is produced by the crater becoming too large to occupy the end only of the positive carbon, and by its, therefore, extending up its side.*

This seems an absurdly simple and inadequate cause to produce such complicated phenomena as those belonging to the hissing arc, but it is the true one nevertheless. Before I proceed to prove this, I will show how the laws for the largest silent currents with normal arcs, which have been already obtained from the electrical measurements on pages 370, 372, and 374, may be deduced on the above hypothesis from Figs. 6 and 7.

In Fig. 6 we have a series of four normal arcs of the same length, burning between solid carbons of the same diameter, but in (*a*) the current is 6 amperes, in (*b*) 12, in (*c*) 20, and in (*d*) 30 amperes. The bluntness of the tip of the positive carbon may be measured by the obtuseness of the angle A B C. In (*a*) the tip is very blunt, and the area of the crater is certainly less than any but the smallest cross-section of that tip; therefore the arc is certainly silent. In (*b*) the tip is less blunt, but the arc is still evidently silent; in (*c*) the angle A B C is much more nearly a right angle, and it is plain that a very small increase in the area of the crater would cause it to burn up the side of the tip, therefore the arc is near the hissing point. In (*d*) the angle A B C is practically a right angle, the tip of the positive carbon is cylindrical, and the crater has evidently burnt partly up its side. Thus, keeping the length of the arc constant and gradually increasing the current must gradually bring us to a hissing point.

Next, I have shown elsewhere[1] that with a constant current the end of the positive carbon becomes rounder and blunter, and occupies a larger portion of the entire cross-section of the carbon rod the more the carbons are separated. Hence, the longer the arc, the greater must be the area of the crater, and consequently the greater must be the current, before the crater extends up the side of the positive carbon. Consequently, the longer the arc, the greater is the largest silent current.

Thirdly, it follows that when the current and the length of the arc have been increased to such an extent that the tip of the positive carbon occupies the whole cross-section of the carbon rod itself, no further increase in the size of the crater is possible without a part of it extending up the side of the positive carbon. Hence the largest silent current

[1] *The Electrician*, 1895, vol. xxxiv. p. 614.

for a positive carbon of a particular diameter cannot exceed a particular value, however long the arc may be made. And lastly, similar reasoning used in conjunction with Fig. 7 tells us that the thicker the positive carbon the greater must be the largest silent current for a particular length of arc, which was one of the results deduced from the curves in Figs. 2 and 3.

Consequently, the fact that hissing occurs when the crater covers more than the end surface of the positive carbon and extends up its side, combined with our knowledge of the way in which the positive carbon shapes itself in practice, is sufficient to enable us to deduce *all* the laws given on pages 370, 372, and 374, which govern the largest current that will flow silently with the *normal* arc under given conditions.

It is also now obvious why, when the arc is *not* normal, it may be made to hiss with small currents or be silent with quite large ones. For suppose, for instance, the end of the positive carbon were filed to a long fine point, then a very small current would make a crater large enough to extend up the side of the point, and produce a hissing arc. Whereas, on the contrary, if the end were filed flat, so as to have as large a cross-section as possible, quite a considerable current could flow silently even with a short arc, for, in that case, it would require the current to be great for the crater to be large enough to fill up the whole of the end of the positive carbon.

We come now to the question, why should the arc hiss when the crater burns up the side of the positive carbon—what happens then that has not happened previously? In pondering over this question, the possibility occurred to me that, as long as the crater occupied only the end surface of the positive carbon, it might be protected from direct contact with the air by the carbon vapour surrounding it, but that, when the crater overlapped the side, the air could penetrate to it immediately, thus causing a part at least of its surface to *burn* instead of volatilising. Many circumstances at once seemed to combine to show that this was the true explanation. The dancing circles I had observed, and Mr. Trotter's stroboscopic images, how were they caused but by draughts getting into the arc? Then the humming noise, which I long ago described as sounding like the wind blowing through a crack, was not this probably caused by the air rushing through a slight breach in the crater already getting near to the critical size? This air, pouring in faster and faster as the breach widened, would cause the arc to rotate faster and faster, sometimes in one direction, sometimes in another, according as the draught was blown from one side or the other. Then finally the air would actually reach the crater, burn in contact with it, and the P.D. would fall and the arc would hiss.

In the open arc, whether silent or hissing, the outer envelope of the vaporous portion is always bright green. With the hissing arc the light issuing from the *crater* is also bright green, or greenish blue. What so likely as that the two green lights should have a common origin, viz.: the combination of carbon with air? For the outer green light is seen just at the junction of the carbons and carbon vapour with the air, and the inner one only appears when air can get direct to the crater.

Again, why does the arc always hiss when it is first struck? Is it not because a certain amount of air must always cling to both carbons when they are cold, so that when the crater is first made its surface must combine with this air?

The cloud that draws in round the crater when hissing begins would be a dulness caused by the air cooling the part of the crater with which it first came into contact, the bright spots being at the part where the crater and air were actually burning together. In fact, everything seemed to point to the direct contact of crater and air as being the cause, perhaps not of the hissing *sound*, but of the diminution in the P.D. between the two carbons, which is the important part of the hissing phenomenon.

One easy and obvious method of testing this theory immediately presented itself. If air were the cause of the hissing phenomena, exclude the air and there would be no sudden diminution of the P.D. between the carbons, however great a current might be used. Accordingly I tried maintaining arcs of different lengths in an enclosed vessel, and increasing the current up to some 40 amperes. *No* sudden diminution of the P.D. could be observed with any of the currents or lengths of arc employed, although when the same carbons were used to produce *open* arcs, the sudden diminution of 10 volts in the P.D. between the carbons occurred with a current as low as 14 amperes for a 1 mm. arc.

Indeed, so far from there being any sudden diminution in the P.D. when the current through an *enclosed* arc is raised to higher and higher values, the P.D. appears to slightly increase for large currents.

It was, of course, impossible, in these experiments, to avail myself of an ordinary enclosed arc lamp, since a current of some 5 or 8 amperes is all that is used with

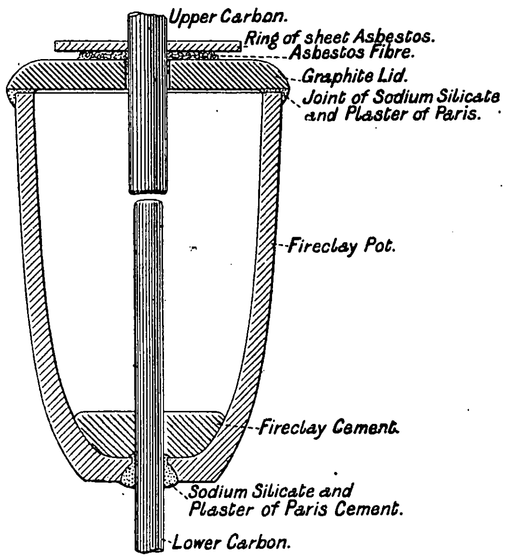

FIG 8.

such a lamp, whereas to test my theory it was necessary to employ currents up to 40 amperes, although my carbons were of smaller diameter than those fitted in ordinary commercial enclosed arc lamps. Accordingly, I constructed little electric furnaces, some made out of fire-clay crucibles with lids of graphite sealed on, as in Fig. 8; some moulded out of fire-clay with mica windows inserted, so that the image of the arc could be projected on to a screen and its length kept constant; some constructed of iron lined with asbestos. Some had tubes inserted in them through which the air could be admitted when required, &c.

It was found that when the vessel was entirely enclosed, the pressure in it was so great, on the arc being first started, that occasionally the lid was blown off. Consequently the space between the positive carbon and the asbestos ring was left open till the arc was well started, and then was tightly closed. This sudden increase of pressure probably took place when the carbons were first *brought into contact*, for Mr. Seaton,[1] while conducting some experiments for Messrs. De la Rue and Müller in 1879, observed that when the arc was completely enclosed the increase of pressure when the carbons were first brought into contact was far greater than could be accounted for by the rise of temperature of the gas in the vessel, and that the pressure fell, the moment the carbons were separated, almost to what it had been before contact was made. This fact was confirmed by some experiments made by Stenger,[2] in 1885. This first great rise of pressure may, of course, be partly caused by the gases occluded in the carbons being expelled on the current being started, but a complete investigation of this phenomenon has not, as far as I am aware, yet been made.

Some curves connecting the P.D. between the carbons with the current when the arc was completely enclosed in the crucible (Fig. 8) are given in Fig. 9. The carbons were solid, the positive being 11 mm. and the negative 9 mm. in diameter, similar to those used with the open arc experiments (Fig. 1). As this crucible—the first one made—had no window, the length of the arc could not be kept quite constant, but the distance by which the carbons were separated was noted at the beginning of the experiment, and they were then allowed to burn away, without being moved, till the end, when the distance the positive carbon had to travel in order to bring it tightly against the negative, was noted. Measured in this way, the length of the arc was 1·5 mm. at the beginning and 2 mm. at the end of the experiment. The current was started at 6 amperes, and gradually increased to 39 amperes; then as gradually diminished to 6 amperes again, increased to 36 amperes, and diminished to 5 amperes, when the arc was extinguished. The P.D. between the carbons for a given current seems to have increased as the length of time during which

[1] *Philosophical Transactions*, 1879, p. 179.
[2] *Wiedemanns Annalen*, 1885, vol. xxv. p. 31.

ARC ENCLOSED IN CRUCIBLE.

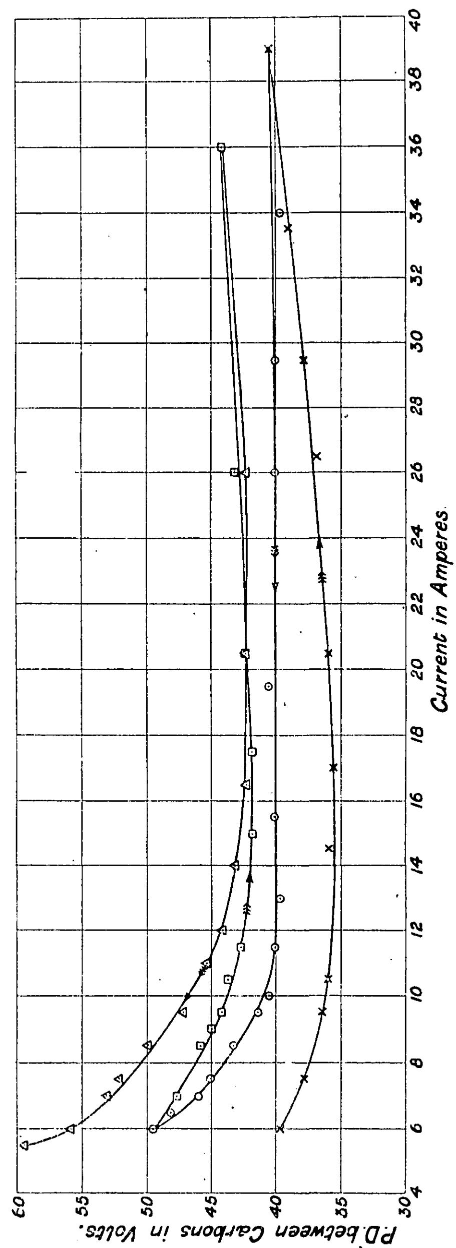

FIG. 9.

Curves connecting P.D. and Current for nearly Constant Length of Arc of 1·5 mm. to 2 mm. The Arrows show the Direction in which the Current was varied.

CARBONS.

Positive, 11 mm. Solid; Negative, 9 mm. Solid.

the arc had been burning increased; this was undoubtedly partly due to the lengthening of the arc, but was probably also partly due to the whole of the air in the crucible having been gradually burnt up, or driven out between the slag wool and the asbestos ring, by the pressure of the carbon vapour.

Many other sets of curves were obtained, but all with the same result, viz., that, when once the crucible had been freed from air, no sudden diminution in the P.D. could be observed on increasing the current far beyond the value at which this diminution occurred on lifting up the lid and allowing the air to have access to the arc.

The next thing to do was to try if an open arc could be made to hiss and the P.D. to suddenly diminish by blowing air against the crater, when the current was so small that the crater remained well at the end of the positive carbon—in fact, to bring the air in contact with the crater artificially, when a much smaller current was flowing than would usually produce hissing. I first tried inserting a carbon tube in the arc and blowing through it, but this almost invariably blew the arc out. Then Mr. Phillips, one of Professor Ayrton's assistants at the Central Technical College, suggested using a tubular positive carbon, and blowing the air down it. This plan answered admirably, for, when a current of 10 amperes was flowing with an arc of about 3 mm., so that the arc was quite silent, each puff of air blown down through the positive carbon was followed by a hiss and the characteristic diminution of the P.D. between the carbons. With a current of 6 amperes, however, I could get no hiss, but simply blew the arc out each time, probably because, with such a small current, the arc was cooled sufficiently to be extinguished before the action could take place.

Oxygen was next tried, still with the open arc, and again each puff produced a hiss and diminution of the P.D., the latter being exactly the same in amount as when air was used, namely, about 10 volts. As my idea was that the diminution of the P.D. was due to the chemical combination of air with carbon at the temperature of the crater, the fact of oxygen producing the same diminution of the P.D. as air seemed to show that nitrogen would produce no effect, and that all the effect produced by air was due to the oxygen in it. Accordingly I tried blowing nitrogen down the positive carbon of an open arc, and found that *no* change in the P.D. followed if the nitrogen was blown through gently, but that, beyond a certain pressure, the arc was blown to one side, and thus lengthened, so that the P.D. *rose*, and, if the pressure continued, the arc went out.

This experiment proved two things—firstly, that it is the *oxygen* in the air that causes the diminution in the P.D. with hissing; secondly, that this diminution in the P.D. is not due to cooling, for nitrogen would cool the arc as effectually as oxygen or air.

To make assurance doubly sure on this point, carbon dioxide was blown down the tubular positive carbon, with the same result as when nitrogen was used, viz., no change was produced in the P.D. between the carbons unless the pressure of the gaseous stream were large enough to blow the arc on one side, and then an increase and not a diminution in the P.D. was observed.

If, however, the current was *very near* the value that made an open arc of the particular length used start hissing, blowing either nitrogen or carbon dioxide through the positive carbon sometimes started hissing; but this was due, *not* to any direct action of the stream of gas on the carbon, but to the arc being deflected by the gaseous stream and burning obliquely up the side of the carbon and thus allowing the air to come into contact with the crater. The proof of this was that this diminution in the P.D. had the same value as if air had been employed, and that the hissing phenomena did not disappear on stopping the stream of nitrogen or of carbon dioxide.

This was not the case with hydrogen, however. When that gas was blown down the positive carbon in the open air, the arc would start hissing if the current were large enough, *and stop hissing the moment the hydrogen was shut off.* Not only this, but the diminution in the P.D. had a different value from that produced by air, being only about 6·5 volts instead of 10 volts. Table IV. gives the current and the P.D. between the carbons just before the hydrogen was turned on, just after it was turned on, just before it was turned off, and just after it was turned off.

TABLE IV.

EFFECT OF BLOWING HYDROGEN DOWN A TUBULAR POSITIVE CARBON.

Carbons : Positive, 11 mm. Tubed ; Negative, 9 mm. Solid ; Length of Arc, about 3 mm.

P.D. between Carbons in Volts.				Current in Amperes.
Before H. was turned on.	After H. was turned on.	Before H. was turned off.	After H. was turned off.	
52	46	46	53	14
52	45	47	52	12
52	45	45	52·2	12
52·5	46	46	53	12
52	45	46	52	9

Thus, the mean diminution of P.D. accompanying the hissing caused by hydrogen being sent down the positive carbon of an arc burning in the air was about 6·6 volts, or about $3\frac{1}{2}$ volts lower than when the hissing was caused by air alone.

In order to exclude all possibility of doubt as to the effect of the various gases, I repeated the experiments with the arc entirely enclosed, so that the only gases that could reach it were those blown down the tubular positive carbon. The current was distinctly below the hissing point, being only 10 or 11 amperes, and the arc was from 2 mm. to 3 mm. long.

When air was blown down the positive carbon, each puff lowered the P.D. by about 10 volts, and the moment the puff ceased the P.D. rose again. Next, oxygen was tried, with the same result. Thirdly, nitrogen with *no* result, or with the result that the arc was blown out if the pressure was too great. Carbon dioxide had the same effect as nitrogen, and lastly hydrogen was tried.

This gas, however, gave a totally different result with the enclosed arc from that already obtained with the open arc. For whereas, as has been previously stated, hydrogen produced a distinct hissing of its own when blown down the positive carbon in the *open air,* it produced *none* when used in the same way with the *enclosed* arc.

To prove that, in order to produce the sudden diminution of P.D. under discussion, it was necessary for the active gas to actually touch the crater, a tubular *negative* carbon was used, and each gas was blown up through it in turn, gently enough not to force the gas directly against the crater.

In *no* case was there any sudden diminution of the P.D., whatever was the gas blown through the negative carbon, and whether the arc was open or enclosed. On the contrary, there was generally a small increase, probably due to the lengthening of the arc by its being blown on one side. If oxygen or air were blown *very hard* up the negative carbon, they would either produce hissing, or blow the arc out, or both; for in that case some of the gas got to the crater uncombined with the carbon vapour, and acted exactly as if it had been blown down the tubular positive carbon.

The case, then, stands thus:

(1) When the arc begins to hiss in the ordinary way, the P.D. between the carbons diminishes by about 10 volts.

(2) If the air is excluded from the arc, this diminution of the P.D. does not take place, even when the current is nearly three times as great as would cause hissing in the air.

(3) If, however, while the air is excluded, puffs of air are sent against the crater, the diminution of the P.D. *does* occur, even with currents much *smaller* than would cause hissing in the air.

(4) If, instead of air, *oxygen* is sent against the crater, the P.D. is diminished to exactly the same extent as when air is used.

(5) If, on the other hand, *nitrogen* is sent against the crater, *no* diminution of the P.D. is observable.

(6) If air or oxygen is gently blown through the *negative* carbon, so that it cannot get direct to the crater, *no* diminution of the P.D. follows.

Thus there can be no shadow of doubt that *the sudden diminution of P.D. that accompanies the hissing of the open arc is due to the oxygen in the air getting directly at the crater and combining with the carbon at its surface.*

This explanation, like many another in science, solves certain difficulties, only to create others which may, perhaps, be yet harder to deal with. Directly we know exactly how the diminution of P.D. accompanying hissing is brought about, we ask, "How does this combination of gas and carbon, at the temperature of the crater, act in producing a diminution of P.D. so sudden, so certain, following such definite laws as those we have been considering? Why do certain gases produce it and not others? Why does hydrogen act in the presence of air, but not when air is absent?" &c.

These are questions that have been occupying me for some time past, and which will, I hope, be completely answered by the series of experiments on which I am still engaged. These latter experiments, although suggested by the investigation on the Hissing of the Electric Arc, have already opened up a different field of inquiry, and the further results may therefore with advantage be reserved for a future communication.

It only remains for me to express my high sense of the honour done me by the Institution of Electrical Engineers in asking me to read this paper, and to thank the many people to whom I am indebted for very kind assistance.

My most sincere thanks are due to Professor Ayrton for much criticism, for advice as to the methods of conducting the experiments, and for invaluable help in the literary portion of the work; to Mr. Solomon for constructing with much ingenuity the first enclosing crucible, and for making the earlier experiments with it; to Mr. Phillips for assisting in the experiments and for drawing most of the diagrams, especially the admirably executed coloured drawings of the hissing and silent arcs; to Mr. Carter for supervising, and to Messrs. Manuel & Pletts for very carefully constructing the apparatus for the experiments of this evening; and lastly, to Messrs. Arundell and Spencer for helping with most of the experiments for the paper, and for conducting many of them alone, with great skill and patience, as well as for carrying out so admirably all those that have been shown to you this evening.

The PRESIDENT: If we followed our ordinary procedure we should at once go to the discussion of the paper to which we have been listening. But I feel that this is not an ordinary occasion, and that the last words spoken by Mrs. Ayrton require me to depart from usage in that respect. Mrs. Ayrton said she felt honoured by the Institution in having been allowed to make this communication. I am sure that we on our part feel more than equally honoured that Mrs. Ayrton has chosen this Institution as the medium of its publication. It is a communication of unusual merit. Based upon elaborate, painstaking, exact experimental observation and upon the clearest reasoning, it forms, I think, quite a model of scientific method in research. The President.

Perhaps before we go to the cold-blooded business of the dissection of the paper I may be allowed to say that I feel astonished at the great progress that has been made, and the perfection that has been realised, in the arc method of electric lighting. I remember the time when the arc light was a new thing, a thing attended with frequent splutterings and hissings and extinctions, not entirely due, as we now know, thanks in a great measure to the research of Mrs. Ayrton, to the defects of the lamps, but due in some considerable measure to defects in the carbons themselves. Carbons at that time were always cut square or octagonal, and out of some hard form of carbon such as we find lining gas retorts. Arc lighting has now reached a perfection that, considering the many circumstances and conditions which tend to the instability of the arc (many of which have been very beautifully illustrated to us to-night), seemed at first impossible of attainment. A degree of perfection has been reached that seemed almost finality until Mrs. Ayrton showed us that probably we may advance still further. I think amongst other practical uses of the discovery—for I can speak of it in no other terms than as a discovery—Mrs. Ayrton has made of the cause of the hissing of the electric arc, we shall probably no longer have those flutes or grooves in the carbons used in connection with lighthouse illumination, and which seem, now that we know the cause of the hissing of the arc, designed with the object of preventing the use of the large currents suitable for such lighting. Furrows in the sides of the positive carbon would seem to be highly provocative of the hissing arc. I am not at this stage going to move a formal vote of thanks: that comes later. I am only going to express, for myself, and I am sure I may also express for you all, our very high appreciation of the honour done us by Mrs. Ayrton in coming here to-night and giving us this most valuable contribution to electrical engineering procedure, the first that we have had placed before us by a lady. I know that she will not desire any departure from ordinary routine on that account, but I must say it has added interest to the paper to know that the difficult and laborious work it sums up has been done by a lady who has many duties and occupations besides those incidental to highly abstract scientific research.

Professor SILVANUS P. THOMPSON: I had hoped that Professor Ayrton would have opened this discussion; but as I do not wish to remain silent on this occasion, I must be allowed to join in the congratulations which you have already voiced, that our Institution Professor Thompson.

Profı Thor

has been the channel through which this very important paper has been given to the scientific world. I am quite sure that Mrs. Ayrton would be the last to desire that we should put her upon any platform of amateurishness by declining to discuss what is so excellent a professional contribution to our particular science, and therefore I propose to take up a point or two in the paper that has been read to us.

In the first place, it is clear that we have now got practically a new definition of the term "hissing arc." Apparently there are several things that a hissing arc may do. It makes a noise. It shows a green colour—that was also a discovery of Mrs. Ayrton's, I think, a few years ago. It spurts; and occasionally, when its spurting becomes extreme, produces mushrooms. It covers the surface of the crater for the time being with a kind of cloud or nebula. And it is accompanied, when produced, by that very distinct drop of potential which has been so large a feature of the electrical measurement.

Now, which of these things is to be taken as the criterion of hissing? I always supposed the noise was to be so regarded, and I am not quite sure it is not so. Suppose an arc to have all, or most, of the characteristics I have enumerated. I am not quite clear from this paper whether it is not still a hissing arc, even although you cannot hear it. Yet, after all, the drop of potential appears to be the important indication, in Mrs. Ayrton's mind, because again and again she pointed out to us how in certain cases it dropped, and in other cases it did not. For example, we had the images of two arcs thrown side by side on the screen. The one we were told was an open arc, and the other an enclosed arc. Presently the current was increased through both of them, and we heard a hissing sound, and we were told it was the open arc which was hissing. But to all appearances it was the enclosed arc that was doing so; it went green, it spurted violently, and, if we had not been told, I should have supposed the drop of potential belonged to that one and not to the open arc. So that the dropping of the potential apparently constitutes the hissing arc; and the turning green, the production of the cloud, and the forming of the mushroom, even if they occur, have nothing to do with the hissing arc *per se*. I hope Mrs. Ayrton will make it quite clear in her reply what is the definition henceforth to be adopted for the hissing arc.

Quite early in Mrs. Ayrton's paper there was a remark made which recalled to me some of the discussions which have taken place upon the physics of the arc in times past. We were asked to look at diagram No. 1, at the lowest line belonging to an arc 1 mm. in length, and Mrs. Ayrton pointed out that if we had it in the silent state we might increase the current up to 14 amperes and no more. Then the instability would set in, and after that we might have a hissing arc of 17 amperes or any amount more; but we could not possibly have an arc either silent or hissing at 15 amperes. It is not the first time that the fallacy —for it certainly is a fallacy—has turned up in the physics of the arc, and Mrs. Ayrton herself has now supplied the antidote. I have had occasion before now—I think it was when Professor Ayrton was bringing the physics of the arc before us—to point out that there has

Professor Thompson.

been in the past a fallacy in some of these matters. With reference to the same diagram, taken from Mrs. Ayrton's earlier publications, we used to be told (and my friend Professor Ayrton will no doubt be able to reply to me on this point, if he has any reply by this time) that if you have an arc and keep the potential difference constant, and then lengthen the arc (which would apparently put in an additional resistance) the current increases rather than decreases. The diagram appears to indicate this. We have, let us say, an 8-ampere current at 55 volts, and the arc little more than 4 mm. long. Lengthen the arc, that is to say, go to one of the higher lines in the series of curves, and at the same time keep the potential difference constant, and, with a 5 mm. arc, we are told that the current increases to 11 amperes. I ventured to point out when that was told to us that it was a fallacy. It was putting the cart before the horse. I pointed out that when you lengthen the arc, you, at the same time, must do something to the external circuit to prevent the potential falling. What you do is to increase the current in order to keep the potential up, and the result is that you have a larger current with the larger arc. At the time the explanation was entirely doubted, and Professor Ayrton would not believe that the argument was that way round; but I am glad to find that Mrs. Ayrton has supplied to-night the missing point, namely, that the behaviour of the arc depends very largely on what is going on in the external circuit; that if you work with a larger electromotive force, putting in resistance so as to limit the current, you may control your arc in various ways. You can get a 1 mm. arc, with a current that would not give an arc of that length with the particular electromotive force on the circuit illustrated in Fig. 1. You can have a 1 mm. arc with 15 amperes, although in the circuit there illustrated you must go from 14 to 17 amperes. Mrs. Ayrton has shown that the slope of the line running down from C depends on the electromotive force and on the resistance of the rest of the circuit. The point C was reached by using a certain definite current, namely, 14 amperes, on an arc 1 mm. long and with a potential difference of about 42 or 43 volts. If you had reached the same point by using a dynamo with double the electromotive force and with pretty nearly double the resistance in the circuit, or with treble or with ten times the electromotive force, and increasing the resistance to get back to the same voltage, with the same length of arc, you would still be at the point C; but the line running down through C would drop through a different angle. The steeper the angle, the greater the electromotive force and external resistance to arrive at that point. If this was an arc in a circuit of nearly constant current with a very large electromotive force and a very large resistance, you might have that line going perpendicularly down, and the end of the horizontal line would then be drawn out further to the left; and you might then have an arc 1 mm. in length with a current of 15 amperes. It is really one of the most interesting points in this whole research, that it has been shown by Mrs. Ayrton herself how the behaviour of the arc is affected by the circuit which controls the voltage at the terminals.

Professor Thompson.

I would like to refer to the very important researches Mr. Trotter made some years ago. I think Mrs. Ayrton underrates one point, viz., the observation Trotter made about the rotation of that curious comma-shaped body. He observed it first with the aid of stroboscopic slits, but he pointed out that it could also be seen without any stroboscopic slits, revolving slowly. The phenomenon of the revolving circles of the arc shown by Mrs. Ayrton is practically the same that Trotter has described as a thing which might be seen with the eye.

Professor Ayrton.

Professor AYRTON : Where did he say it ?

Professor Thompson.

Professor THOMPSON : He certainly showed it to me in his own laboratory, but I cannot refer to any paper where it has been mentioned.

I had intended to refer also to the question of the shapes of carbons. Mrs. Ayrton's remarks absolutely prove now that the hissing of the arc is intimately connected with the crater creeping over the edge of the carbon, and this obviously bears the inference that square carbons are to be deprecated.

There remains, of course, a great deal yet to be discussed. For example, though it is evidently proved, thanks to Mrs. Ayrton's researches, that the hissing of the crater is connected with the access of oxygen, complicating the effects at the crater surface with direct chemical action, yet there is a good deal more behind that to explain ; namely, why that action should of itself set up instability, the hissing sound, and the drop of potential. Some years ago I likened this phenomenon of the hissing of the arc to that which occurs when you attempt to cause evaporation to take place from a liquid by putting heat into it at a rate too great for the available amount of surface, when you have the phenomenon of boiling with, or without "bumping." The contrast between the evaporation from the top layer of surface pure and simple and the production of vapour, not only at the top surface, but a little below, heaving up the surface with bubbles, or in the case of solids like camphor or sal-ammoniac producing a disintegration of the surface, is so like that which happens physically in the spurting of the arc, that I cannot help thinking there is something of that nature taking place, and that the access of oxygen is responsible for the disintegration going on below the top surface layer of the crater.

Let me conclude by again expressing my very high appreciation of the remarkable piece of work which Mrs. Ayrton has presented to us, and which obviously represents many months, if not years, of laborious and truly scientific work.

Mr. Mordey.

Mr. W. M. MORDEY : The paper under discussion is, I think, a record of a thoroughly philosophical investigation which will have important results both practically and theoretically, affecting the physics of the arc, not only from the point of view of the student of pure physics, but also from that of the electrical engineer. After all we, as electrical engineers, want arc lamps to give light, and the interesting physical questions that have been dealt with by Mrs. Ayrton are interesting to us particularly because of their bearing on the light-giving power of the arc.

I would ask Mrs. Ayrton to make it clear whether instability is always and necessarily an accompaniment of hissing. If it is not, then, of course we need not always mind if an arc does hiss. As to the references just made to the fluted carbons that are used in lighthouses, we must remember that these fluted carbons, although they may hiss, add to the useful effect of the arc by allowing the light to get out horizontally. One of the drawbacks in arc lights is that the light is given off mainly from the surface of the crater, and that the surface is only to a small extent usefully directed to the object under illumination. On that account Sir James Douglass, a former member of this Institution, introduced the fluted form of carbon when he was Engineer to the Trinity House, and I believe it is now always used in the lighthouses round our coast. I have been in a lighthouse when the light was on, and the arc was hissing the whole of the time; but yet there was a good, steady, useful beam. Mr. Mordey.

These lighthouse arcs, so successful for so many years, are alternate current arcs. To-night we have listened to a work on direct current arcs. There is a large field to be explored (and, as I hope, to be explored by Mrs. Ayrton), in connection with the alternating current arc. I hope that, some day, Mrs. Ayrton will give us a paper here not only on the hissing, but also on the physics of the alternating current arc and on its light.

If I may be allowed to go beyond the scope of this paper, I would draw Mrs. Ayrton's attention to a peculiarity I have noticed in connection with the dark space corresponding with the middle of the arc with alternate currents. It is seen, for instance, on an ordinary 14-inch globe as a dark band about 1½ or 2 inches wide. Now, with a low-period alternate current arc, with, say, 50 periods per second, there is a steady pulsation that is not connected, as far as I can tell, with the periodicity. The periodicity, of course, is far too high to be observed by the eye, but if that dark band is observed, it will be seen to increase and decrease in breadth with a regular beat or pulsation at a rate of about 400 times a minute. But, as there are with a 50-period current 6,000 currents a minute, there is no obvious connection whatever between that slower beat and the periodicity itself. I may say that I have tried by various experiments to ascertain the cause of it, but without success. It has nothing to do with the mechanism—it occurs when the carbons are clamped perfectly steady. It has nothing to do with the electro-magnet in the circuit—I have tried it when there was no electro-magnet in the circuit.

Might I ask Mrs. Ayrton to explain the cause, if it is known, of the more granular appearance of the luminous surface of the carbons in the enclosed arc? It is very marked, and I should like to know what the explanation is. I wish, in conclusion, to repeat my very great appreciation of Mrs. Ayrton's results, and of the admirable way in which she has put them before us.

The PRESIDENT: I have to announce that the scrutineers report the following candidates to have been duly elected:— The President.

Associate Members:

James Alexander Bell.	Major P. R. Burn-Murdoch, R.E.

Foreign Member:

Paul Fournier.

Associates:

Henry Thornton Hazzledine.
Harry Henderson.
Alfred George Jackson.
John Daniel Murphy.
Ernest Hugh Rainbow.
Charles Walter Torrens.
Archibald Wright.

Students:

John Frederick Avila.
Kenneth Chas. Horton Newman.
John Albert Ross.
Thomas Gregory Smith.