



XLI. The relighting of the carbon arc

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XLI. *The Relighting of the Carbon Arc.* By J. A. POLLOCK,
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*B.Sc.**

[Plates IX. & X.]

1. *Introductory.*

WHEN the arc between fixed carbons, in a hand-fed lamp, burns itself out, it may be restarted if too great an interval of time is not allowed to elapse, by lessening the distance between the carbon terminals, but without bringing them into contact. Again, if the circuit is broken and reclosed after a short time, the arc may reestablish itself without the carbons being moved.

In connexion with this latter point, Mr. Upson† has given observations of the maximum times of interruption of the circuit within which the arc will restart, for different arc-lengths and for various previous currents, with carbon-carbon, and with copper-carbon arcs in air, and states that in the circumstances of his experiments copper-carbon arcs in coal-gas and in hydrogen did not restart.

The relighting of the arc after a given time of interruption depends, however, not only on the previous current and on the arc-length, but also on the potential-difference established between the electrodes at the moment of reclosing the circuit,

* Communicated by the Authors: read before the Royal Society of New South Wales.

† Upson, *Phil. Mag.* xiv. p. 126 (1907).

and the object of our experiments has been to find the relation between this latter factor and the time interval, for carbon-carbon arcs in air at natural pressure, under various conditions.

The maximum time of interruption of the circuit, under given conditions, within which the arc will reform on re-making the connexions, is astonishingly well-defined, and could in our observations be determined to $\cdot 002$ second. If the interval between the break and the make of the circuit exceeds what may be called the critical time for the given circumstances, after reclosing the circuit a small non-luminous current passes between the carbons; the heating effects associated with this current are not sufficient to maintain the electrodes at their high temperatures, and the current soon dies away as the temperatures diminish. From considerations advanced in a previous paper* with reference to the establishment of the cathode fall of potential which is such a characteristic feature of the developed arc, one is led to think that, on reclosing the circuit, this smaller current always precedes the larger one of the fully formed discharge; the problem of critical relighting is then essentially that of the change from a non-luminous to a luminous current under the circumstances of the experiments.

In the relighting of the arc both carbons are at a high temperature, and the conditions are complicated by the presence, at the moment of reclosing the circuit, of ions at the anode surface as well as near that of the cathode. Simpler conditions are associated with the change of current régime when only the negative carbon is incandescent; this case, involving, previous to the formation of the arc, the flow of negative electricity from a hot to a cool carbon, has been investigated by two of us †, and an explanation reached which seems to account for the phenomena observed.

In the present experiments, it will be seen that the flow of negative electricity at the moment of reclosing the circuit is not always from a hot to a cooler carbon; the conditions of the change from the non-luminous to the luminous discharge are, therefore, in some instances, more complicated than those in the case previously considered, and the explanation of the development of the arc suggested in the paper just mentioned is not sufficient to account for all the features observed in this investigation. Further data are required before a complete description can be given.

* Pollock & Ranclaud, *Phil. Mag.* March 1909.

† Pollock & Ranclaud, *loc. cit.*

The conditions associated with a change from the non-luminous to the luminous discharge, in the case of the ordinary carbon arc, are seen in the wave-forms of current and potential-difference in connexion with alternating-current arc-lamps.

Fig. 1 (Pl. IX.), showing curves of the volts at the brushes of the machine, of current in the circuit, and of the potential-difference between the carbons of the lamp, is copied from fig. 14 of a paper by Mr. Duddell and Professor Marchant on Experiments on Alternate Current Arcs by aid of Oscillographs*, in which many other illustrations will be found.

The curves may be described by saying that the potential-difference between the carbons rises from zero, while the current keeps low and non-luminous, until the potential-difference reaches the value, p , necessary to change the state of the current to that of the arc-discharge. The current then rises very rapidly, while the potential-difference falls so that a greater electromotive force may be available along the rest of the circuit, a necessary condition if the increase in the current is to be maintained. On the falling side of the wave, the second maximum of the potential-difference seems to be connected with the gradually diminishing current, rather than with any abrupt change in the nature of the discharge.

The current curve is unsymmetrically placed with reference to the zero points of the potential-difference curve, because on the rising side of the wave the change is from a non-luminous to a luminous discharge, when on account of the smallness of the previous current the temperatures are low, whereas on the falling side the change is in the opposite direction, when, owing to the previous larger current, the temperatures are higher.

2. Experimental Detail.

For all the experiments Conradty carbons, Marke C, were employed; both positive and negative were solid, each 13 millimetres in diameter, the lamp being hand-fed. A heavy pendulum, operating two switches when allowed to swing, opened and again closed the circuit; the distance between the switch levers could be readily altered. The time interval between the opening and the reclosing of the circuit for different lengths between the levers was carefully determined by separate experiments carried out as follows:—The switches

* Duddell & Marchant, Journ. Inst. Elect. Eng. xxviii. p. 1 (1899).

were arranged to open and close the circuits of two electromagnetic scribes which marked a smoked plate fixed to the pendulum; the records for various distances between the switch-levers were then compared with that on the same plates of a style attached to the prong of a standardized tuning-fork. A third key, also worked by the pendulum, enabled the battery connexions to be reversed in the interval between the break and the make of the circuit if desired.

A scheme of the connexions is shown in fig. 2 (Pl. IX.), where A is an ammeter, V a voltmeter, R a variable resistance, B the arc, and X and Y the two switches.

An observation consisted in finding, for a given potential-difference between the carbons at the instant of the reclosing of the circuit, the greatest distance between the switch-levers for which the arc would relight. This maximum distance could be determined to within two millimetres, which corresponds to a time interval of about $\cdot 002$ second. The time interval corresponding to the maximum distance may be called the critical time for relighting under the given conditions. This time, under otherwise fixed circumstances, varies considerably with the carbons used, and the results are only directly comparable when they refer to the one pair of carbons.

The observations were made in all cases with "normal" arcs*. The lengths of the arc were measured, on images of the carbons, vertically from the point of the negative to a horizontal line passing through the edge of the crater, the values obtained being reduced according to the magnification of the image.

3. *Relighting with Carbons in Normal Position when Potentials Reversed.*

When the connexions from the battery are reversed during the interval between the opening and closing of the circuit, so that at the remake of the circuit the still existing crater becomes negative to the previous cathode, the crater being on the upper carbon, the phenomena are simpler than in other cases, and will therefore be the first described.

In fig. 3 (Pl. IX.) is shown the relation between the minimum potential-difference for relighting and the interval between the break and the make of the circuit, under the condition of the reversal of the potentials of the carbons, for a previous current of 10 amperes. Three curves are drawn, from observations with the same pair of carbons, for arc-lengths of

* Mrs. Ayrton, 'The Electric Arc,' p. 104.

1.3, 1.9, and 3.1 millimetres respectively, the upper electrode being the positive before the break of the circuit.

In this instance, on reclosing the circuit, the hot is negative to the cooler carbon; the conditions under which the arc is formed are, therefore, nearly allied to those in the simple case previously investigated, see Section 1. The longer the interval between the break and make of the connexions, the lower are the temperatures of the carbons at the moment of reclosing the circuit; taking the fall of temperature of the carbons after the arc is extinguished as nearly proportional to the time, the curves in fig. 3 may be considered as giving, approximately at least, the form of the relation between the critical potential for relighting and the temperature of the hot negative, the temperature of the other electrode being of less importance in this particular case. From this point of view one would expect the curves in fig. 3 to be like those in fig. 7 of the previous paper*, which give the exact form of such a relation under somewhat the same conditions as those under consideration. A comparison shows that the two sets of curves are similar in shape.

Under the conditions of the experiment, the first effect of reclosing the circuit is no doubt a small current of negative ions flowing from the hot to the cooler carbon, and from this non-luminous current the arc may be considered to develop. In the fully formed arc the cathode fall of potential indicates an accumulation of positive ions near the cathode surface. These positive ions, in the growth of the discharge from the non-luminous current, must come in the first instance from the anode. If I is the current of negative ions, E the potential gradient at the anode surface, and λ the length of the last free run of the ions at the end of which they collide with the anode, the energy reaching the anode surface per second is $IE\lambda$; following the suggestion contained in the paper referred to, it is considered that for the arc to form, in the circumstances here contemplated, the potential-difference between the carbons, at the moment of reclosing the circuit, must have the value necessary to make the magnitude of $IE\lambda$ sufficient to raise a portion of the anode surface to such a temperature that positive ions are somewhat freely emitted.

For this particular experiment the suggestion seems sufficient to account for the phenomena observed, but it will be seen that it is not of itself adequate to completely describe the features of the relation in other cases, even where, on reclosing the circuit, the hot is negative to the cooler carbon.

* Pollock & Ranelaud, *loc. cit.*

4. *Effect on the Relighting of Changes in the Relative Positions of the Carbons.*

The form of the relation between the minimum potential-difference for relighting and the time interval between the break and the make of the circuit is influenced by many conditions. With the carbons in a vertical plane they may be situated, before the circuit is broken, either in the normal way, with the crater above, or in the reverse position with the crater below the negative electrode; in addition, the connexions to the battery may be reversed during the interval between the break and the make of the circuit, or left unaltered, so that there are four cases to be considered in connexion with the relative positions of the carbons and the direction of the potential-difference on the remake of the circuit.

In figure 4 (Pl. IX.) are shown the relations between the minimum potential-difference for relighting and the time interval of interruption of the circuit for the four cases mentioned, the current having been 10 amperes when the connexions were broken and the arc-length 1·3 millimetres. The diagrams of the carbons drawn beside each curve indicate by their shape the relative positions of the electrodes before the circuit was opened, while the signs of the potentials, on the reclosing of the circuit, are shown by the usual symbols. All the observations were taken with the same pair of carbons, so the curves are strictly comparable.

Case 4 is the one just discussed in section 3. It is seen that for small time intervals between the break and the make of the circuit, it requires greater potential-differences to restart the arc in the cases 1, 2, and 3 than in that of 4, and that cases 2 and 3 approximate to that of 4 for large intervals of time. Considering that the arc develops from a small non-luminous current of negative ions, an idea which we think must form the basis of any explanation of the critical relighting, in searching for a description of the differences between the curves it has to be noticed that in some cases the negative electrode, on the remake of the circuit, is hotter than the positive, in others the reverse; it is also essential to recognize that in some instances the negative stream of ions is opposed by the convection current of hot gas, while in others it is helped by it, as it has been shown in the previous paper that a change in the relative directions of the stream and current considerably affects the potential-difference necessary for arcing.

The feature of the relations is the evidence, shown by the

curves for cases 2 and 3, of a critical change in the conditions for relighting occurring when the potential-difference attains the value of 90 volts. After reaching this value the minimum potential-difference requisite to start the arc remains for some time practically constant in spite of the fact that for increasing time intervals between the break and the make of the circuit the temperatures of the carbons are diminishing.

The excess of the potential-differences for relighting required in case 1 over those in case 4, for the same time intervals, may be accounted for, perhaps, by the much lower temperature of the negative electrode on the reclosing of the circuit in the former instance, but we have been unable to find, with the data at hand, an explanation of the critical characteristic of the curves for the other cases.

5. Critical characteristic as affected by Arc Length and previous Current.

With a view to finding the influence of arc-length and previous current on the critical characteristic of the curves just mentioned, further observations have been made in connexion with case 3, in which the carbons are in the normal position and the battery connexions remain unaltered during the interval between the break and the make of the circuit. The measurements are given in figures 5, 6, and 7 (Pl. IX.), the currents previous to the break of the circuit being marked on the curves. The observations were thoroughly interlocked with reference to change of carbons, so the curves are comparable.

A comparison of the relations given in figures 5, 6, and 7, shows that the characteristic bend in the curves is more pronounced the higher the previous current. Greater currents mean larger masses of heated carbon with consequent higher temperatures for equal intervals between the break and the make of the circuit.

It is also seen that the greater the arc length, the higher the potential-difference at which the characteristic bend occurs.

6. Photographs of the Relighting.

By arranging an additional lever, in connexion with the pendulum apparatus previously described, to open the shutter of a photographic camera at a short interval after the remaking of the connexions of the arc circuit, photographs showing stages in the development of the arc have been

obtained. The growth of the arc takes place in such a short time that a definite adjustment of the lever was found to be impossible, and the photographs given are only a few of many that have been taken, the remainder showing either no arc, or the arc fully developed.

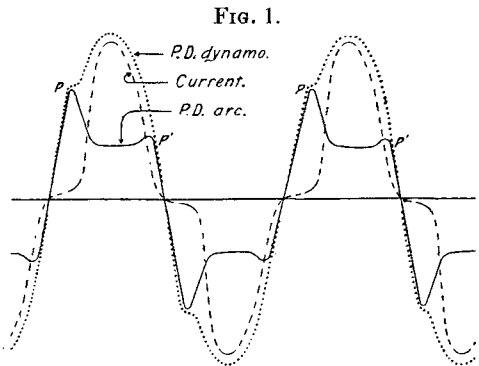
Figures 1 to 7 in Plate X. show stages in the growth of the arc when the circuit is opened and reclosed without alteration of the battery connexions, while figures 8 to 11 refer to cases where, on the reclosing of the circuit, the still existing crater is negative to the previous cathode. In both instances the glow is seen to develop from the electrode which is positive on the remake of the connexions, a fact which seems to support the view taken in this and the previous paper as to the mode of growth of the arc from the non-luminous discharge. Figure 12 is an example of many of the photographs, showing that, in the case of the reversal of the connexions, the new crater commences on cool rather than on hot carbon.

7. Summary.

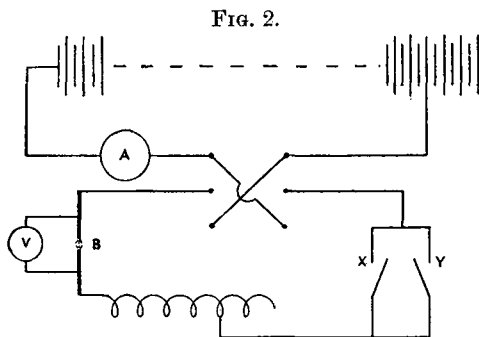
In connexion with the relighting of the carbon arc, without movement of the electrodes, when the circuit is opened and reclosed, the relation between the potential-difference, established between the carbons at the moment of the remaking of the connexions, and the maximum time of interruption of the circuit, within which the arc will reform, has been investigated for cases differing as to the relative positions of the carbons before the opening of the circuit, and as to the direction of the potential-difference after the reclose of the connexions. The problem is that of the change from a non-luminous to a luminous discharge in air at normal pressure, of which an explanation, in the case where negative electricity flows from a hot to a cool carbon, has been given in a previous paper. In the present experiments both carbons are at a high temperature, and the conditions of the change are complicated by the presence, at the moment of reclosing the circuit, of ions at the anode surface as well as near that of the cathode. In some of the cases examined the relations show a critical characteristic, but sufficient data are not available to enable an explanation of this result to be given.

We are indebted to Mr. H. L. Watkins, B.A., and Mr. L. A. Cotton, B.A., B.Sc., for help in connexion with the earlier part of the investigation.

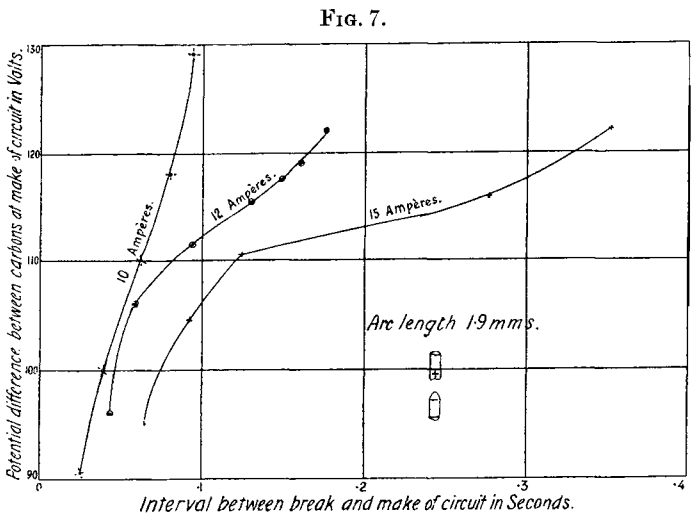
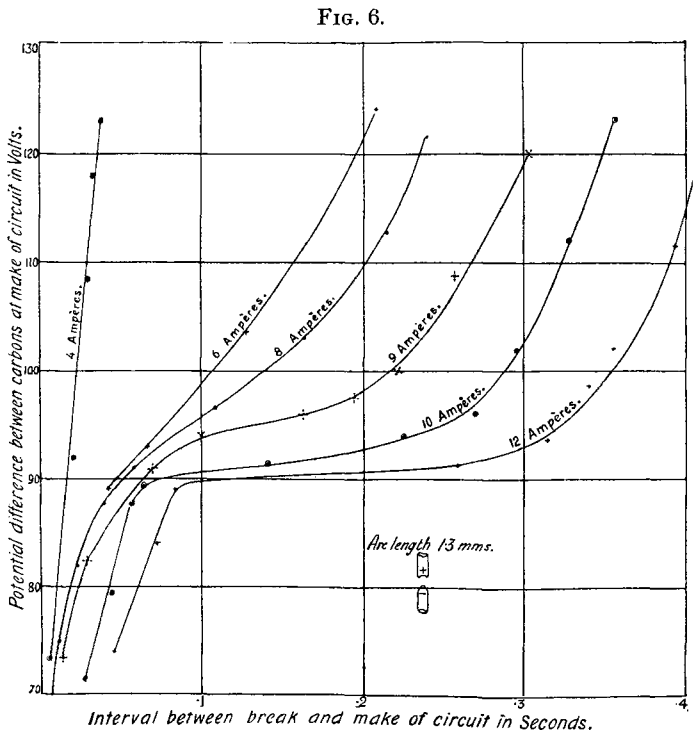
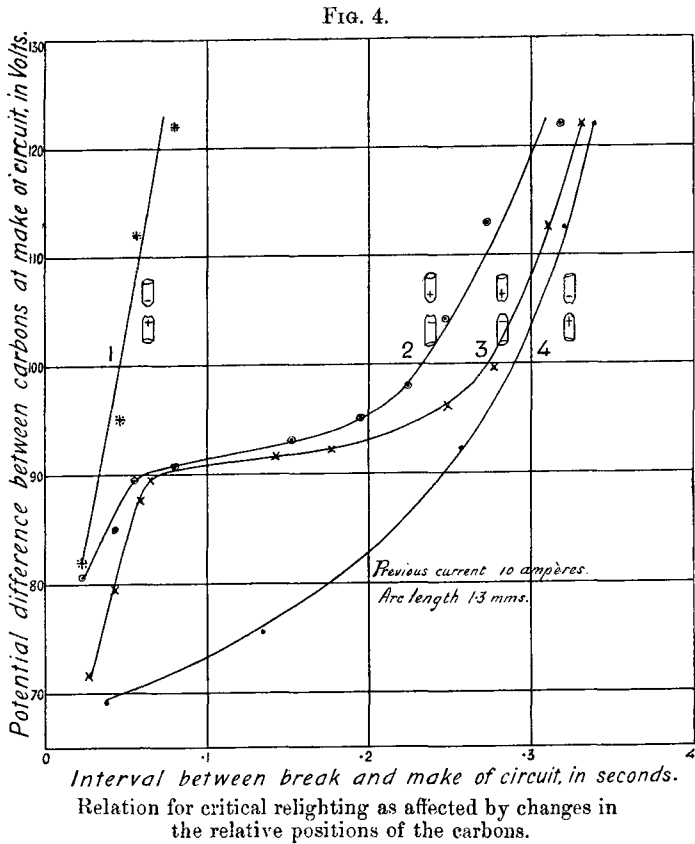
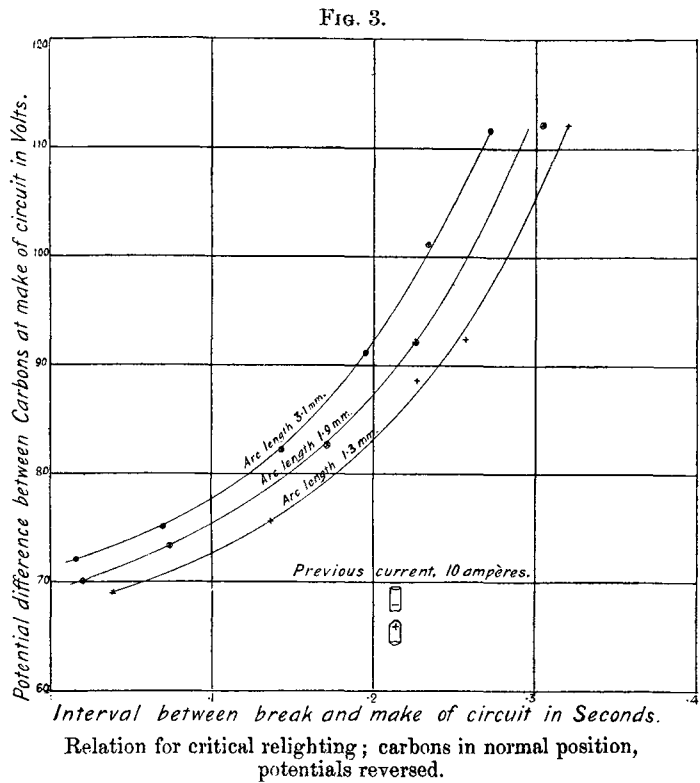
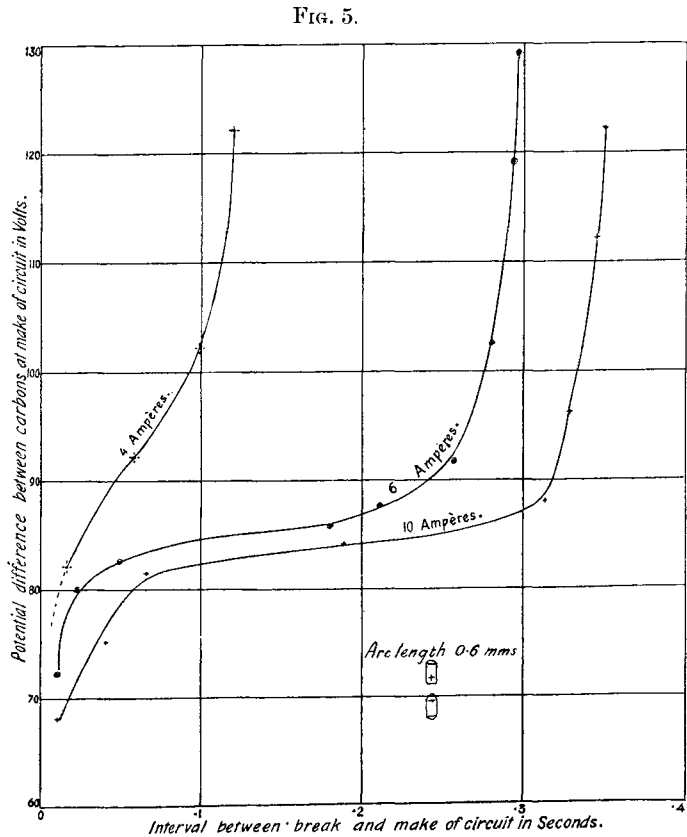
The Physical Laboratory,
The University of Sydney,
September 2nd, 1908.

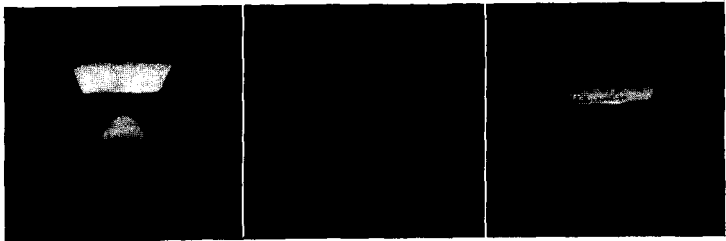


Waves of current and potential-difference in connexion with an alternating-current arc-lamp.—Duddell & Marchant.



Scheme of connexions.

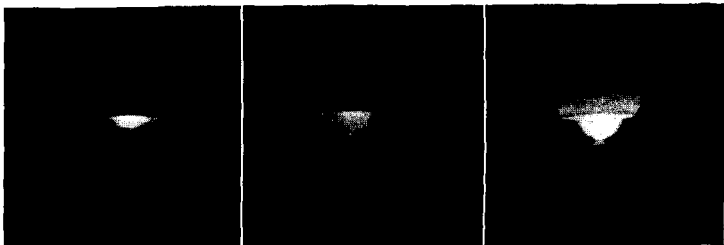




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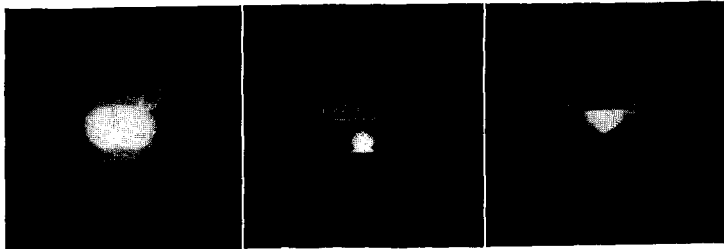
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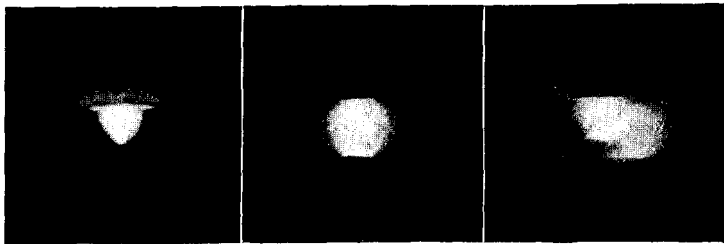
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