THE STRIKING POTENTIAL IN THE LOW-VOLTAGE MERCURY ARC

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ABSTRACT

Striking potential in the low-voltage mercury arc.—(1) *Variation with vapor pressure.* A tube with a thoriated tungsten filament and a nickel anode over a reservoir of mercury was heated in an electric furnace. When a constriction was placed in the tube leading to the pump so as practically to eliminate streaming of the vapor, and the temperature raised, the striking potential decreased to a minimum of approximately 5.3 volts for a pressure corresponding to a mercury surface temperature of 160°C and then increased. When no constriction was present, a similar curve was obtained except that on account of the streaming the pressure for a given furnace temperature was lower and hence the minimum was not reached below 320°C. If the fact that the vapor was fresher in the second case had any influence, it was not evident. (2) *Variation with the distance away of mercury surface.* When streaming was prevented, the same striking potentials were obtained for the same vapor pressures whether the surface was 5 cm or 80 cm from the arc. These results are somewhat at variance with those of Yao and suggest that further investigation is necessary.

PART I

THE experiments here described were undertaken in order to obtain more definite knowledge regarding the characteristics of the low voltage arc and in particular regarding the factors upon which the striking potential depends. An effort was made to obtain as steady conditions as possible in the experimental tube with particular attention to securing gas-free apparatus, a good vacuum, and a conditioned filament that would yield a constant electron emission.

The plan of the original set-up used in these experiments is indicated in Fig. 1. The anode was a platinum wire (8 mil.) and the filament consisted of two parallel thoriated tungsten wires (10 mil.) about 15 mm long. The whole tube was completely enclosed in an electric furnace, whose temperature could be maintained constant within two or three degrees and was read by means of a mercury thermometer placed as indicated. The filament current was supplied by a set of storage batteries and was varied by means of a series resistance, the value being read on a shunted milli-voltmeter. The applied potential for striking the arc was obtained from a potentiometer arrangement and was measured by a Weston voltmeter. In all the work the potential was applied first from the anode to the positive end of the filament and then from the anode to the negative end of the filament. In the curves, the average value of the potentials obtained with these two connections is plotted as the striking potential. The variation of the electron current or the arc current was observed by means of a galvanometer.

A second type of tube contained a cylindrical nickel anode in place of the platinum wire and had mounted upon the anode a thermo-junction by means of which the temperature of the anode could be obtained. A third type of tube, otherwise similar to the second, possessed a thermo-junction for measuring the temperature of the mercury near its surface.

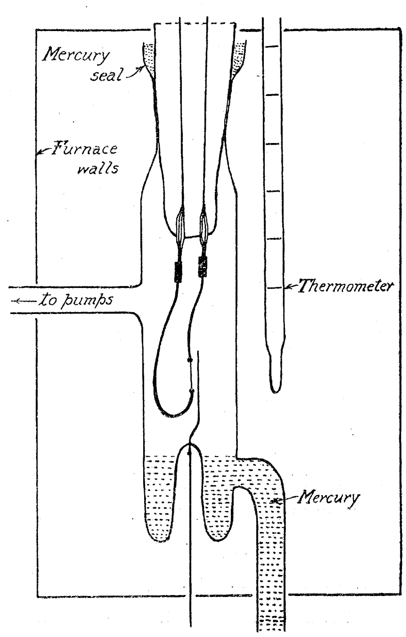

Fig. 1. Original apparatus

Before any measurements were made, the pumps, a mercury vapor pump combined with a Hyvac fore-pump, were kept operating while the apparatus was baked at 300° C, and the filament was glowed at a current higher than that to be used during the experiment. When the current in the anode-filament circuit remained constant for a period of two or three hours, the filament was considered ready for use. Another test was to strike the arc for an instant at intervals of several minutes and observe when the striking potential became constant. The arc must not be maintained for this will increase the striking potential measured during the succeeding few seconds.

The initial work consisted in a study of the variation in the striking potential with filament current, and before the report of the work by Compton and Yao,[1] results similar to theirs had been obtained by the writer, but were not reported because it was felt that the filaments then used, with their heavy currents, were not as yet sufficiently constant in their emission. This work covered not only the striking potential but also the breaking potential, and these results check well with Yao's published curves.[2] It has never been found possible to strike the arc at less than 5.5 volts, when initial velocities are considered, even though the arc may be maintained at well below 2 volts.

The difficulty in studying the variation in the striking potential with vapor density is to determine the value of the vapor density. Since condensation occurs in the side tube of the pump, there is a pressure gradient from the liquid surface to this tube. Also the filament is extremely hot and tends to decrease the vapor density in the region of the anode, which is probably the region of chief importance in striking the arc. It is, therefore, difficult if not impossible to get more than an idea of just what the vapor density is. Nevertheless it was felt worth while to obtain data, recording the temperature as given by the mercury thermometer and the corresponding striking potential.

The method of taking a set of data was to adjust the furnace current to give a desired value of the temperature and then to take readings of the temperature and the striking potential every five minutes until the temperature remained constant within 2 or 3 degrees and the striking potential within .1 volt. The operation was repeated at other temperatures. The temperatures chosen ranged from 70° C to 300° C, and readings were taken not only in steps of increasing temperature but also in steps of decreasing temperature. It was found that the striking potential was constant within .1 volt at a given temperature.

While many sets of data were taken, only one is completely plotted in Fig. 2, for that is typical of all the results obtained with the first and second types of tube. It is seen that above a certain temperature, 150° to 180° depending on the filament current, the striking potential decreases rather slowly but more or less uniformly with increasing temperature. If this decrease continues to higher temperatures, it would be possible to strike an arc at less than 5.5 volts. With regard to this point reference should be made to the work of Stead and Stoner on "Low-Voltage Glow in Mercury Vapor."[3] They found that the glowing potential, which

[1] Compton and Yao, Phys. Rev. **20**, 105, 1922

[2] Yao, Phys. Rev. **21**, 1, 1923

[3] Stead and Stoner, Proc. Camb. Phil. Soc. **21**, Feb. 1922

must certainly correspond to the striking potential of the arc, decreases more or less uniformly with increasing temperature from 15° C to 150° C and then rises. With the apparatus here described, it was impossible to go much above 300° C. It is not known whether the vapor pressure for 300° C was actually greater than that corresponding to 150° C, but it seems very probable that it was, in spite of the more rapid streaming of the vapor into the side tube at the higher temperatures.

The experimental tube used by Stead and Stoner was sealed from the pumps so that the mercury vapor was in equilibrium with the liquid, while in the writer's tubes, there was a streaming of vapor into the side tube, which became pronounced at temperatures above 150° C.

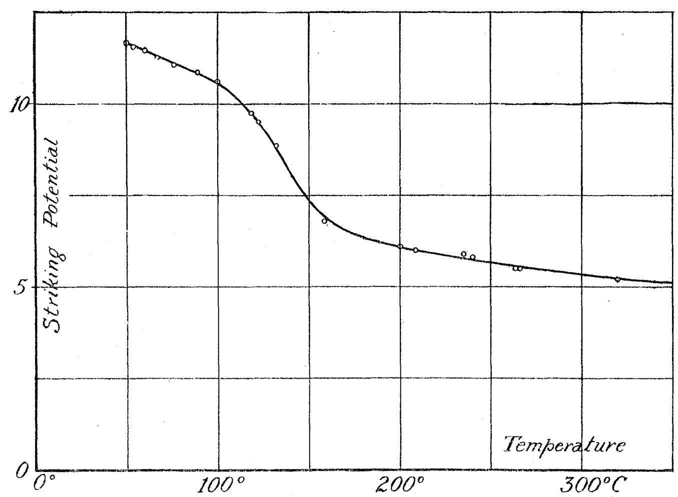

Fig. 2. Variation of striking potential with the temperature indicated by the mercury thermometer

It seems that the difference in the results obtained must be assigned to some factor that enters with the streaming of the vapor.

In order to reduce the uncertainty in the value of the vapor density, the third type of tube with the thermo-junction in the mercury was adopted. A difficulty developed at once, for due to the condensation in the side tube, there was a net evaporation from the liquid surface, which produced a large temperature gradient just below the mercury surface and extending downward for about one-half inch. Also the glass was hotter than the mercury and this set up convection currents in the mercury, and made the thermo-junction unsteady so that the temperature could not be accurately obtained. To eliminate these difficulties, it was planned to seal off the tube from the pumps at a point inside the furnace. With this in mind, a tube was inserted with a constriction for sealing off, and trial experiments were made with the pumps still connected. It was found that the constriction had eliminated condensation so far as our measurements were concerned, the thermo-junction became steady, and the mercury no longer possessed any temperature gradient at its surface.

Sets of data were taken in the manner previously described, and the results are shown in Fig. 3. The striking potential is plotted against the temperature as given by the mercury thermometer (curve A) and also as given by the thermo-junction (curve B). The difference in these temperatures is due to the high heat conductivity of the mercury column. The type of variation differs from that shown in Fig. 2 only at temperatures above 150° C and shows the same general character as the result obtained by Stead and Stoner.

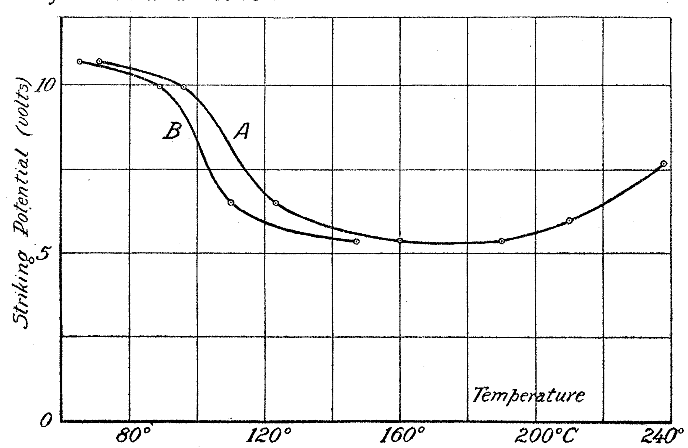

Fig. 3. Variation of striking potential with (A) mercury thermometer temperature, (B) thermo-junction temperature

It may be that the shape of the curve in Fig. 2, obtained with the first and second types of tube, can be explained on the basis that the increase in temperature and hence vapor pressure at the liquid surface produces a greater velocity of flow of vapor from the surface and results in younger vapor being present at the anode. Consequently on the basis of Yao's result that the striking potential is less with younger vapor, the striking potential would decrease with increase in temperature of the mercury surface, if this effect outbalanced the one evident in Fig. 3.

With the second type of tube it was found that if the arc were struck and maintained at a high voltage for a few seconds, the anode would become hot and the striking potential would increase as much as .3 volts; then, if the arc were struck at intervals of a few seconds, the striking potential would decrease with the temperature of the anode, until they both reached their earlier values. This might be due either to a decrease in vapor density in the neighborhood of the anode or to a decreased electron emission of the filament after bombardment by the positive ions. Since Hebb observed a decrease in striking potential, when the platinum anode was heated, the effect is probably due to a decreased emission.

It is to be noticed in Fig. 2 that the striking potential—temperature curve consists of two more or less straight portions connected by a transition curve. While the data covering the whole range of temperatures were being taken, it was observed that the arc struck definitely and vigorously at temperatures below 85° C and also above 140° C. In the range between, the striking of the arc was attended by two or three potential drops as the applied potential was raised. At 100° C the first drop was most prominent but as the temperature was increased, the last one became relatively important until at 140° C it alone remained.

Since these facts were observed time after time it seems reasonable to assume that two types of arc are involved—the one existing at the lower temperatures and the second at the higher temperatures. It may be that at the lower vapor pressures the mercury entities find themselves in a condition sensitive to stimulation of the 6.7 volt type of radiation in preference to the 4.9 volt type, while at the higher vapor pressures the reverse is the case.

Part II

Y. T. Yao[2] recently described experiments to show that the striking potential of the low-voltage arc in mercury depends upon its distance from the liquid surface. It was found that the striking potential increased when the arc was struck in vapor at increasing distances from the surface. This result was expected on the basis of the work by Van der Lingen and Wood[4] on the fluorescence of mercury vapor.

These experimenters found that during distillation, the mercury vapor close to the liquid surface, when stimulated, radiates strongly light of wave-length λ2536 and that the intensity of the radiation depends upon the rapidity of the distillation and becomes faint when the vapor is in equilibrium with the liquid. It is to be expected, therefore, that this vapor during distillation will also favor the striking of the arc at a lower voltage. It is evident that the vapor is fresher on the average when distillation occurs than when the vapor is in equilibrium with the liquid. In some of his experiments, Yao seems to have taken precautions to prevent vapor streams and hence to obtain vapor in equilibrium with the liquid—a case which, on the basis of the above-described

[4] Van der Lingen and Wood, Astrophys. Jour. **54**, 149, 1921

experiments, might be expected to produce a condition favorable for striking the arc at a lower voltage only if the striking potential is a more sensitive test of the age of the vapor than the phenomenon of fluorescence.

In order to investigate farther under what conditions there is a variation in the striking potential with distance from the liquid surface the type of apparatus shown in Fig. 4 was adopted. It consisted of a cylindrical, nickel anode with a thoriated tungsten filament along the axis. A platinum-platinum rhodium thermo-junction was inserted at the upper and lower positions of the mercury level, in order that the temperature and hence vapor pressure of the mercury might be accurately known. In order that the two levels chosen might correspond to a large ratio of the distances from the liquid surface, a helix of 3/8 inch glass tubing was sealed in between these positions. These distances were 5 cm and 80 cm approximately. The whole was completely enclosed in an electric furnace and a mercury thermometer was inserted with its bulb opposite the anode so that the temperature could be read.

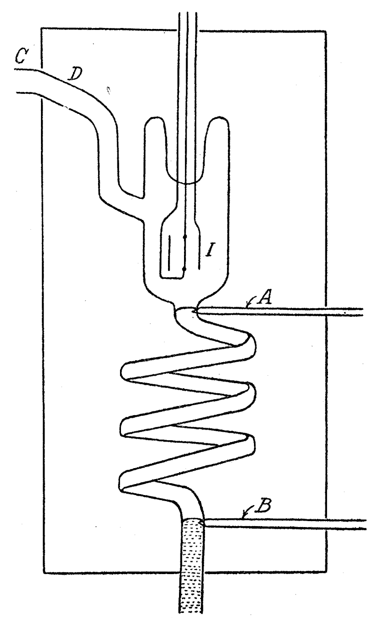

Fig. 4. Later apparatus

The treatment of the apparatus preparatory to an experiment was the same as described in Part I.

The experiment consisted in raising the mercury level to *B*, then while all conditions were maintained constant, in observing the striking potential at regular intervals until it was definitely determined within .1 volt. Next the mercury level was raised to position *A* and the process repeated. In general, the striking potential corresponding to position *A* was lower because the temperature of the mercury surface was higher, being higher in the furnace. Finally, the temperature of the furnace was lowered until the thermo-junction at *A* read the same as the one at *B* during the first step. The process of observing the striking potential at regular intervals was again repeated, other factors being kept constant, until the striking potential became constant within .1 volt. Sometimes the mercury level was first raised to position *A*, then lowered to position *B* and the furnace temperature increased so that the temperature of the liquid surface was the same as it had been for position A. In Table I, the results for this order of procedure are indicated by a star.

In the apparatus, as indicated in Fig. 4, condensation was bound to occur in the side tube to the pump at C, but as there was a positive temperature gradient from the bottom to the top of the furnace, and as the mercury was always at a lower temperature than that of the furnace, no condensation could ever take place elsewhere than at C. This condensation introduced a pressure gradient for the mercury vapor and since the distance IA was much smaller than the distance IB, the vapor pressure at I was bound to be much greater when the mercury level was at A than when at B, provided the temperature of the mercury surface was the same in both cases. It was therefore expected that the striking potential would, for this set-up, be lower when the mercury level was at A than at B.

Table I summarizes data, which were taken with the apparatus as described. By change in furnace temperature is meant the change in temperature necessary to maintain the mercury surface at the same temperature for the level A as for the level B.

TABLE I
Results with streaming vapor

No.	Position	Temp.	Change in furnace temp.	Striking potential	Difference
1	B	110° C	15	8.92	2.2
	A	110° C		6.72	
2	B	119	9	6.97	1.2
	A	119		5.8	
*3	A	127	10	5.52	.8
	B	127		6.3	
*4	A	133	5.5	5.37	.5
	B	133		5.87	

It is seen that the difference in striking potential can be made as small as .5 volts for the ratio of distances employed, and in view of the difference in vapor pressure at the anode in the two cases, practically all of this difference might be assigned to that cause. These data then do not seem to allow of a more definite conclusion than that the striking potential difference might be accounted for by the difference in the vapor pressures and that the striking potential may or may not be a function of the distance from liquid surface to the anode.

The next step consisted in inserting a constriction in the side tube at point D (see Fig. 4) with the intention of sealing off the tube from the pumps. In order to make sure that no great gas pressure would develop so that the arc would behave erratically when the pumps were disconnected, the striking potential was observed at five minute intervals for a period of two or three hours after the tube had been disconnected from the pumps by a mercury cut-off. The striking potential during this time did not change by more than .1 volt.

With this constriction in the side tube, it was found that at temperatures below 150° C the condensation in this tube was practically eliminated so that over a period of hours no visible drop of mercury collected here, while without the constriction a steady collection was easily observed. Under these circumstances, then, the pressure gradient was practically reduced to zero, even without sealing off from the pumps, and with this in mind, the experiment was repeated as previously described. Observations were made at three different temperatures. The results are tabulated in Table II.

TABLE II

Results with constriction in connection to pumps

No.	Position	Temperature	Striking potential
1	B	70.5	10.15
	A	101.0	7.97
	A	70.5	10.15
2	B	105	7.0
	A	105	7.0
3	B	146	5.07
	A	146	5.07

It is seen that when the temperatures of the mercury surface were the same for the two positions so that the vapor pressures were the same, the striking potentials were identical within .1 volt. The conclusion to be drawn is two-fold: first, that the striking potential is not appreciably more sensitive than the phenomenon of fluorescence for detecting the younger vapor; second, that in mercury vapor which is in equilibrium with its liquid, the striking potential is not a function of the distance to the liquid surface, at least for the distances used.

It would seem that further experimentation is necessary to prove that the striking potential depends upon the age of the vapor and that the striking of the arc may be used to indicate that the young vapor in a stream is especially sensitive to $\lambda 2536$ stimulation.

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