

THE ELECTRICAL CONDUCTIVITY OF A BUNSEN FLAME
FOR SMALL DISTANCES BETWEEN THE ELECTRODES.

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IF two platinum discs are immersed in a flame, and a potential difference maintained between them, a current will flow through the flame, and it can easily be measured by means of a galvanometer. The usual method of measuring the conductivity of a flame has been to employ a very long flame, consisting of a row of small burners side by side, and two platinum disc electrodes which can be moved about in the flame. It has been found¹ that there is a uniform potential gradient in the part of the flame from the anode close up to the cathode, while close to the cathode there is a large fall of potential. The relation, found by H. A. Wilson, between the current through the flame, the distance between the electrodes, and the potential difference, is given by

$$(1) \quad V = ACd + BC^2$$

where V represents the potential difference; C , the current; d , the distance between the electrodes; and A and B are constants. The term ACd is due to that part of the flame in which there is a uniform potential gradient, and the term BC^2 to the fall of potential near the cathode. According to this formula, which is derived experimentally¹ when d is large, and theoretically² on the assumption that the current is far from saturation, C should be independent of d when d is small, V being kept constant. However with the above mentioned apparatus, any departure from this formula when the electrodes are brought close together, would be masked by the current around the backs of the electrodes, which would give a value of the distance much larger than the real distance between the electrodes. The object of the following work was, therefore, to eliminate this conduction around the backs of the electrodes and thereby get the true distance effect, and to see if there is any departure from the above formula when d is small.

APPARATUS AND METHOD.

The arrangement of the apparatus used in the experiments is shown in Fig. 1. The air, kept at a constant pressure, as shown, and the gas,

¹ H. A. Wilson, *Phil. Mag.*, Oct., 1905, p. 476.

² J. J. Thomson, "Conduction of Electricity through Gases," 1906, p. 92.

with a manometer in its inlet tube, were fed into a mixing chamber *m.c.*, and then to the burner. The gas used was gasoline vapor. This gave a steady, hot, flame, which kept the electrodes, *e*, at a yellow to white heat. A brass cylinder was placed about the lower part of the flame to steady it. The electrodes, of which there were three, were connected as shown in the diagram. The outer electrodes were connected together, and could be moved together and apart by means of a micrometer screw of 1 mm. pitch, with its head divided into 100 parts (Fig. 2).

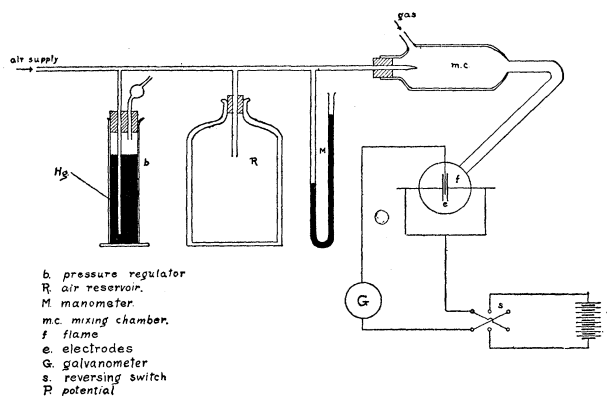


Fig. 1.

One electrode was fastened to a block worked by a right-hand screw, and the other to a block worked by a left-hand screw, both screws being cut on the same shaft. The central electrode was a disc about 10 mm. in diameter, cut from sheet platinum, with a strip projecting out of the flame for support. This electrode, which was the cathode in all of the experiments, was kept fixed, and the outer electrodes moved up to it. The discs were carefully paralleled, and so it was possible to work at very small distances.

During the preliminary experiments it was found that, unless the electrodes were scrupulously clean, the galvanometer would rush to a very high value when the circuit was closed, and gradually drift back. It would take about twenty minutes to reach a steady value. The decay of the current with the time was apparently exponential. When the current was stopped and again started, the galvanometer rushed off as before, again drifting back. Therefore, in order to clean the electrodes thoroughly, they were boiled in HCl for several hours, and then heated in the flame for a considerable time before beginning any experiments. After this treatment it was found that, upon closing the circuit, the current went immediately to a steady value.

The use of the compressed air supply was found necessary, for, in the preliminary experiments, with an ordinary burner with exterior air inlet, salt puffs from the dust in the air were rapidly admitted to the flame,

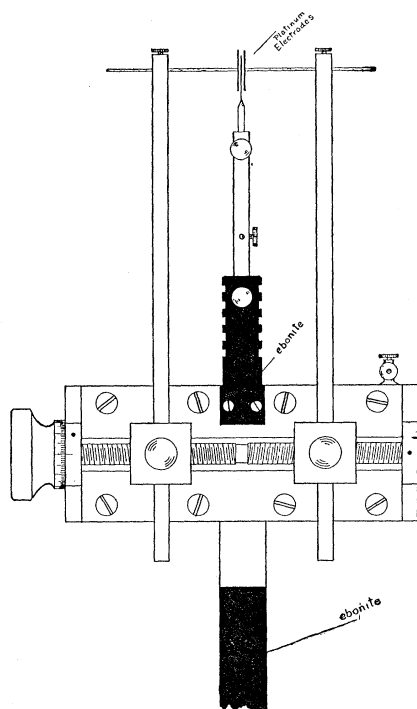


Fig. 2.

keeping the galvanometer constantly jumping about. The potential was furnished by a battery of small dry cells giving about 150 volts per 100. These are shown at *P*. In order to measure the distance between the electrodes, the reading of the micrometer was taken at an unknown distance, and the micrometer then moved until the electrodes touched, as indicated by the galvanometer flying off the scale. The micrometer was again read—the difference giving the distance between the electrodes. Protective resistances of CuSO_4 in glycerine were provided for the galvanometer. As a check on the constancy of the flame, before beginning any set of readings, the electrodes were set at a certain standard distance apart and a standard potential applied. The

resultant current was never found to vary more than 5 per cent.

RESULTS.

The variation of the current through the flame with the distance between the electrodes was first observed—the potential being kept constant. It was found at distances less than 1 cm., that, as the distance was decreased, the current decreased, reached a minimum at about .6 mm., and, as the distance was further decreased, rose rapidly to a high value. This was observed for a number of values of the potential difference, from 1.5 volts up to 300 volts. Typical curves, showing this variation of the current with the distance between the electrodes, are shown in Fig. 3.

If the formula $V = ACd + BC^2$ held for all values of d , then for small values of d , the curve should be as represented by the dotted line, Fig. 5. This equation, as before stated, is derived on the assumption that the

current is far from saturation. As the distance becomes smaller, however, the number of ions between the electrodes becomes smaller, and there is then more likelihood of saturation. If the current should reach

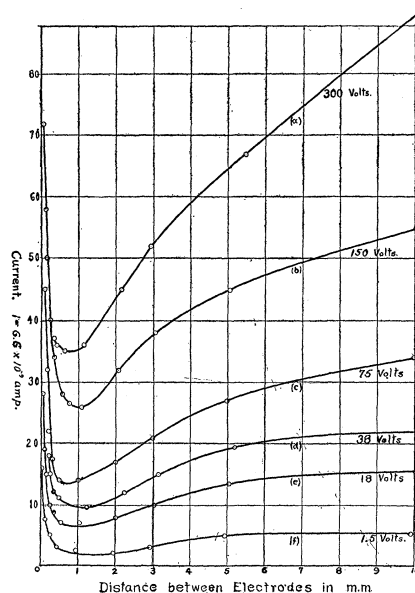


Fig. 3.

a saturation value, then a decrease in d would produce a decrease in C . To see if the current had really become saturated when the electrodes were close together, the electrodes were fixed at about .2 mm. apart, and the variation of C with V observed. The relation is shown in Fig. 4. It appears from this curve that the current has apparently about become saturated when the potential is above about 15 volts. For distances greater than 0.5 cm. the curves showing the variation of C with V were found to be approximately parabolas, showing that at these distances the above formula was beginning to hold. It is then fair to suppose that this decrease in C , as d in decreased, is due to a decrease in the number of ions between the electrodes. But why should the current reach a minimum and then rise again? The first explanation that suggested itself was that ionization by collision had begun to take place; but this idea soon failed, for the variation of C with V at very small distances gave a curve similar to Fig. 4, while if ionization by collision had begun to take place, it would be expected that the curve should rise again. Moreover, the rise in C , as d approached zero, was obtained with potentials as small as 1.5 volts, which is too small to produce ionization by collision. The

ionization by collision theory was then discarded, and the effect explained as follows.

It is well known that when a body is raised to incandescence, ions are emitted from its surface. The currents carried by these ions may be made fairly large when the incandescent body is placed in a vacuum, but

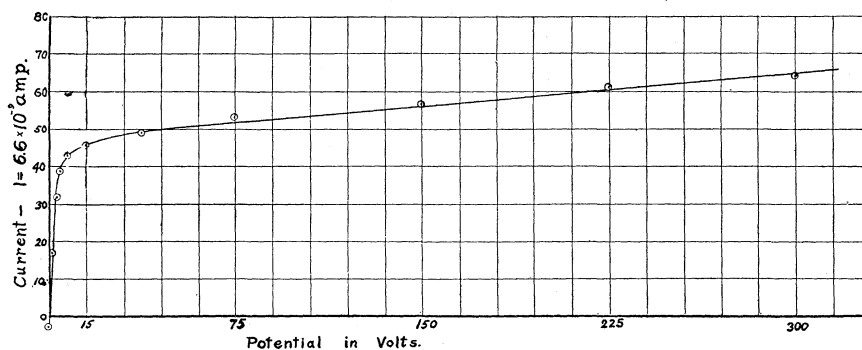


Fig. 4.

when a gas is present, the motion of the ions is retarded and some of them diffuse back to the incandescent electrode.

Let I be the maximum possible thermionic current from the hot electrode, and i the actual current observed. Now assuming that when an ion strikes the electrode it gives up its charge, and that the current

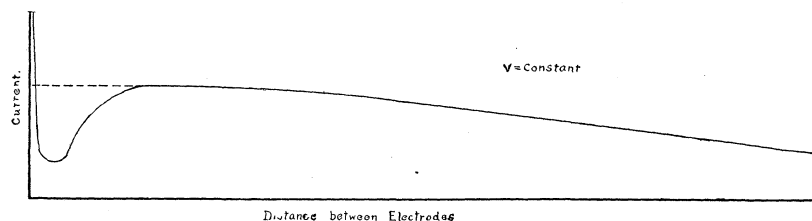


Fig. 5.

due to volume ionization in the gas is so small as to be negligible, $(I - i)$ will represent the charge carried back per second by diffusion. If there are n ions per cc. close to the electrode, then on the kinetic theory of gases, the number of ions striking it per sq. cm. per sec. is

$$\frac{nu}{\sqrt{6\pi}},$$

where u is the velocity of agitation of the ions. We then have,

$$I - i = \frac{nue}{\sqrt{6\pi}}.$$

Since $i = kneX$ and $k = 1.4 e\lambda/mu$, where X is the field intensity; λ , the mean free path, and m , the mass of the ion, the equation becomes,

$$i = \frac{IX}{X + \frac{mu^2}{1.4 e\lambda/6\pi}}^1$$

Since mu^2/λ is independent of the temperature, we can replace it with a constant, so that $i = IX/(X + B)$, where B is a constant.

Now if we assume that, for small values of d , the field is uniform, we have

$$\frac{V}{d} = X,$$

so that

$$i = \frac{IV}{V + Bd}$$

or

$$i = \frac{I}{1 + Bd/V}.$$

This equation is that of a rectangular hyperbola shifted slightly to the left along the d axis. However we have neglected the volume ionization due to the gas. This is proportional to the distance between the electrodes as long as the current is saturated, so that

$$(3) \quad i = \frac{I}{1 + Bd/V} + Cd,$$

where C is a constant, and the term Cd represents the current due to volume ionization.

These curves (Equation 3) have minima and are very similar to the experimental curves for small values of d . However, as d becomes large, the current is no longer saturated, and the curve bends over instead of approaching the line, $i = Cd$, asymptotically. That is to say C is not a constant except when d is small.

The actual values of the current when d was less than about .2 mm. could not be relied upon for calculations, because of the magnified effect of small irregularities of the surfaces of the electrodes. The determination of I was therefore not attempted.

SUMMARY.

The variation of the current through the flame with the distance between the electrodes was investigated, and found to be as shown in Fig.

¹ H. A. Wilson, "The Electrical Properties of Flames and of Incandescent Solids," p. 40.
J. J. Thomson, "Conduction of Electricity through Gases," 1906, p. 208.

3. As d is diminished, the decrease in the current was shown to be due to the current becoming saturated, and the volume decrease causing a decrease in the current. The curve reaches a minimum and then rises again. This rise is explained by the intense field increasing the thermionic current, and was shown not to be due to ionization by collision. The relation between the current and the distance between the electrodes for all values of d is shown in Fig. 5.

In conclusion I wish to express my most sincere thanks to Prof. H. A. Wilson, F.R.S., for his kindly interest in these experiments, and for his valuable advice during the investigation.

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