CATHODE FALL IN NEON.

BY ARTHUR H. COMPTON AND C. C. VAN VOORHIS.

SYNOPSIS.

Systematic measurements have been made of the potential difference between the cathode and the beginning of the positive column when a discharge is passed through pure neon, using a number of different metals as cathode. The "normal cathode fall," or potential difference between the cathode and the cathode glow for normal current, was also determined for several metals. It was found that for normal current the potential difference between the cathode and the positive column is very nearly proportional to the potential difference between the cathode and the cathode glow when different metals are used as cathode. The values of the normal cathode fall in neon were found to be, with Pt cathode 152 volts, W 125 v., Tl 125 v., Al 120 v., Mo 115 (?) v., Mg 94 v., Ca 86 v., Na 75 v., and K 68 v. These values are in the order, as far as available data go, of the contact potential series, and are consistently slightly lower than the corresponding values in helium.

THE recent studies of H. A. Wilson[1] and C. A. Skinner[2] have emphasized the importance of a thorough experimental knowledge of the electrical characteristics of low pressure discharge tubes. The potential drop at the cathode, which is of especial theoretical significance, has been investigated by a large number of experimenters, including Hittorf,[3] Skinner,[4] Wilson,[5] Mey[6] and Defregger.[7] The results of the early experiments were often uncertain because of impurities in the gas and on the surface of the electrodes. Mey and Skinner have both made systematic studies of the cathode fall for a number of different metals in various gases. In most of this work, however, the gases hydrogen, nitrogen and oxygen were employed, which makes the significance of the results somewhat doubtful on account of danger of chemical action by the gases on the electrodes. Certain similar experiments by Mey, Defregger and Watson[8] have been performed in inert gases, but for the most part the tests were isolated ones, which makes an accurate comparison of the results for different metals of doubtful value. For

[1] H. A. Wilson, PHYS. REV., 8, 227, 1916.
[2] C. A. Skinner, PHYS. REV., 12, 143, 1918; 9, 97, 314, 1917.
[3] Hittorf, Wied. Ann., 20, 705, 1883; 21, 133, 1884.
[4] C. A. Skinner, loc. cit., and Wied. Ann., 68, 752, 1889; Phil. Mag., 8, 387, 1904.
[5] H. A. Wilson, Phil. Mag., 49, 505, 1900.
[6] K. Mey, Ann. d. Phys., 11, 127, 1903.
[7] R. Defregger, Ann. d. Phys., 12, 662 (1903).
[8] H. E. Watson, Proc. Camb. Phil. Soc., 17, 90, 1913.

this reason we undertook a systematic investigation of the cathode fall of a number of different metals in neon. This gas, besides being chemically inert, has the valuable characteristic of showing in its spectrum the presence of small traces of impurities, which makes it possible to be sure that uncontaminated gas is being used.

In any work of this character, the final value of the investigation depends upon the purity of the gas and the freedom of the surface of the cathode from any film of foreign material. The neon used was prepared by Claude and was very kindly loaned to us by the Bureau of Standards. It was enclosed in an all glass system, being circulated by the help of a mercury pump and a number of carefully constructed stopcocks. Though initially practically free from any impurity except water vapor and a trace of helium, the neon was subject to contamination by the gases given off from the electrodes of the discharge tubes. The

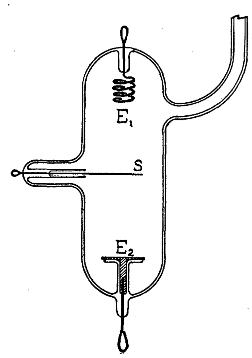

Fig. 1.

hydrogen thus introduced was burned by circulating the gas through a small bulb containing an oxidized copper wire heated electrically to a dull red. Final purification was secured by passing the neon through freshly-baked, activated cocoanut-charcoal, cooled in liquid air. All impurities other than helium were thus completely absorbed, and the pressure of the neon over the charcoal was so reduced that it was possible to pump back into the reservoir practically all the helium with the first portions of the neon, leaving behind gas which showed in a spectrum tube no impurity of any kind.

A typical form of discharge tube is shown in Fig. 1. It consists of a glass tube 3.5 cm. in diameter in which were sealed two electrodes E_1 and E_2 and a small sound wire S. It was found from previous experiments that in a discharge tube of this diameter the positive column begins about 4 cm. from the cathode when the pressure and current are such as to give the normal cathode fall. For this reason the tubes were made with electrodes 8 cm. apart and the sound wire placed midway between, so that either one could be used as cathode. These tubes were highly exhausted and baked for several hours at 500° C. before the neon was introduced. The special treatment required to secure clean metallic surfaces on the electrodes will be described below as each different metal is considered.

The electrical system employed may be explained from Fig. 2. The source of the current was a 500-volt direct current generator whose

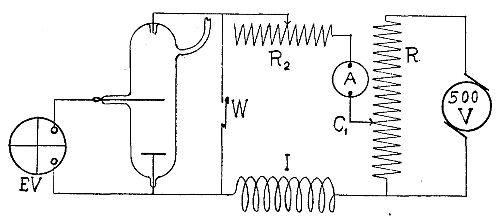

Fig. 2.

terminals were connected across the 2,500-ohm resistance R_1. By varying the voltage across the discharge tube with the sliding contact C_1, and by means of the widely variable resistance R_2, current varying in magnitude from 0.00001 to 0.2 ampere could be obtained. The resistance R_2 consisted of a variable length column of a solution of alcohol in xylol in series with a metallic high resistance. By momentarily shorting the circuit with the wire W and then breaking it again, the discharge could be started due to the action of the inductance I, which was the secondary of a small 2,200 volt transformer. The current strengths were measured by the milliammeter A, and the potential differences by means of an electrostatic voltmeter of special design EV.

Measurement of the Potential Drop from the Positive Column to the Cathode.

Preliminary experiments showed that there is a minimum potential difference between the cathode and the sound wire, placed as described above, for a certain value of the current. This minimum value is practically the same over a rather wide range of gas pressures, and the current strengths giving the minima vary approximately as the square of the pressures, just as for the cathode fall. Consequently for each different gas pressure in a given tube a series of readings of the potential drop was taken as the current strength was varied, and the minimum values were taken as the ones to be used in making comparison with other metals. The voltages as thus determined were practically independent of the pressure of the gas for pressures between 2.5 and 15 mm. of mercury. The values of the potential differences between the positive column and the cathode which are given below for each of the different metals are the average of a large number of measurements at different pressures in this range.

Aluminium, Magnesium, Calcium.—Thin flat discs of these metals were used as cathodes in bulbs similar to that shown in Fig. 1. In order to clean the surface and eliminate the absorbed hydrogen, these cathodes were maintained at a high temperature (about 600° C.), by means of a discharge in neon at low pressure, until the spectroscope revealed no impurities in the neon after continued operation. The mean value of the minimum potential drop from the beginning of the positive column to the cathode was found for aluminium to be 140 volts, for magnesium 115 volts and for calcium 102 volts.

Platinum, Tungsten, Molybdenum.—Sheets of pure platinum and tungsten, having been cleaned by raising them to a white heat in rarified neon, gave corresponding potential drops of 175 and 140 volts respectively. Cathodes of commercial tungsten wire (1 or 2 per cent. thorium oxide) and of pure molybdenum wire coiled in loose spirals were also employed. These gave for tungsten, 123.5 volts, and for molybdenum 133.5 volts. The difference between the two tungsten cathodes may perhaps be partly accounted for as due to the thorium oxide impurity in the wire, but is also probably due in part to the difference in shape of the two electrodes. If this is the case, the voltage observed in the case of molybdenum is not strictly comparable with that observed for the other metals.

Thallium.—A clean electrode of this metal was obtained by splashing the molten metal about in an atmosphere of pure neon. The minimum potential was found to be 145 volts.

Alkali Metals.—Clean cathodes of sodium, potassium and their alloy were obtained by vacuum distillation in a tube of the form shown in Fig. 3. The metals having been inserted in bulb *B* were distilled successively into bulbs *D* and *F*, and bulb *D* was sealed off at *E*. Neon was then admitted into bulb *F*, the alkali metal was melted and the neon was pumped out, bringing with it the clean molten metal. The minimum potential drop from the anode glow to the cathode in the case of sodium was 87 volts, for potassium 77 volts and for an alloy containing about equal weights of the two metals, 84 volts.

The Normal Cathode Fall.

In order that our results might be comparable with those of other observers, we measured directly the "normal cathode fall" from the cathode glow to the cathode for a number of different metals. For this purpose an extra sound wire was sealed into the discharge tube about 8 mm. from the cathode in such a manner that it was in the cathode glow when the normal current was passed through the tube. The current giving the minimum value for the cathode fall under a certain set of

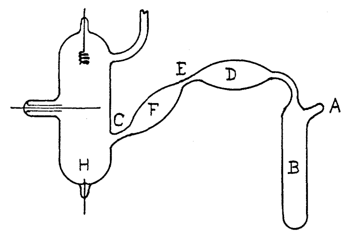

Fig. 3.

conditions was found to be practically the same as that which gave the minimum value for the potential drop between the cathode and the positive column. The values of the normal cathode fall C and of the minimum potential drop P from the positive column to the cathode are given in columns two and three respectively of Table I.

Table I.

Metal.	C.	P.	Ratio C/P.
Platinum................	152 volts	175 volts	0.87
Magnesium..............	94	115	.82
Calcium................	86	102	.84
Na-K Alloy.............	73.6	84	.88
Potassium..............	68	77	.88
			0.86 mean

It will be seen in the third column of this table that the ratio of the normal cathode fall to the fall in potential from the positive column is for these metals constant within the probable experimental error. It is therefore possible to calculate from our measurements of the minimum potential difference between the cathode and the positive column the value of the normal cathode fall for the different metals in neon by multiplying the former quantity by the factor .86. The values of the normal cathode fall as thus estimated are given in the second column of Table II.

Table II.

Metal.	Normal Cathode Fall.	
	In Neon.	In Helium.
Platinum	152	160 (D) 165 (Dm)
Tungsten	125	
Thallium	125	
Aluminium	120	141 (D)
Molybdenum	115(?)	
Magnesium	94	125 (D)
Calcium	86	
Sodium	75	80 (M)
Na-K Alloy	73.6	78.5 (Dm)
Potassium	68	69 (M)

Discussion of Results.

We have no data available which determine the positions of tungsten, thallium, molybdenum and calcium in the contact potential series. For the remaining metals, however, our results are in accord with Skinner's hypothesis that the cathode fall varies inversely with the electropositiveness in the contact potential series.

The values quoted for the normal cathode fall in helium are those given by Defregger (D), Dember (Dm) and Mey (M). It will be seen that the cathode fall in neon is uniformly slightly lower than in helium. This is of interest in connection with the fact that the ionizing potential of neon is slightly lower than that of helium.

Research Laboratory,
Westinghouse Lamp Company.