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SECONDARY EMISSION FROM METALS DUE TO BOMBARDMENT OF HIGH SPEED POSITIVE IONS

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Abstract

A beam of K^+ ions from the iron catalyst source discovered by Kunsman was collected in a Faraday cylinder. A target could be interposed at the mouth of the cylinder by a magnetic control. The difference in current measured in these two cases gave the amount of secondary emission. A transverse magnetic field could be applied at the target to prevent emission of electrons and thus separate electron emission from positive ion reflection. The percentage secondary emission due to bombardment of positive ions having speeds up to 1000 volts has been found for three metals; viz., aluminum, nickel, and molybdenum under a variety of surface conditions. Heat treatment in general reduced the secondary electron emission. The secondary electron emission could not be detected (was less than 0.5%) at positive ion velocities less than 200 volts for Al, 300 volts for Ni, and 600 volts for Mo after heat treatment. The secondary emission increased from these values to 7.0% for Al, 4.2% for Ni, and 3.8% for Mo at 1000 volts. Without heat treatment the emission was detected at lower voltages and reached about double the above values at 1000 volts. The secondary electrons emitted were of low speed, a retarding field of a fraction of a volt was enough to stop nearly all of them. In the cases of molybdenum and nickel positive ion reflection did not exceed 2%, and was undetectable in the case of aluminum.

Introduction

MANY investigators have undertaken the measurement of electron emission from metallic surfaces due to the bombardment of positive ions, but the results obtained have not been in agreement. The purpose of the present work is the measurement of the emission from various metals by using different kinds and speeds of positive ions and by following a method the results of which will be unequivocal. We have endeavored to separate the phenomenon of positive ion reflection from electron emission, a matter which has not received much attention on the part of many workers in the field.

Among the early workers on this problem was Villard,[1] who found that cathode rays are formed by positive ions impinging on the cathode. A few years later J. J. Thomson[2] found that when alpha rays from polonium bombarded a metal, many slow speed electrons were emitted.

Füchtbauer[3] has shown that negative rays are given off when a metal is hit by canal rays, and that the velocity of the negative rays is inde-

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[1] Villard, Journ. de Phys. **8**, 1 (1899).

[2] Thomson, Proc. Cam. Phil. Soc. **13**, 49 (1904).

[3] Füchtbauer, Phys. Zeit. **7**, 153–157 and 748–750 (1906).

pendent of the velocities of the canal rays. If 30,000 volt canal rays bombard metals in all cases electrons are emitted, aluminum giving three electrons for each canal ray and platinum giving one electron.

In this connection mention should be made of the work on delta rays by Campbell,[4] Bumstead,[5] and McLennan and Found.[6]

Later work by Cheney[7] did not take account of positive ion reflection. He obtained a secondary emission of about 9 percent from aluminum bombarded by 600 volt potassium ions and about 2.5 percent for platinum using the same kind and speed of ions. He says nothing concerning the treatment given the metal surface.

Secondary emission due to canal rays going through thin gold foil was measured by Hahn.[8] He found that the emission grew with increasing speed of the primary particles. A measure of the velocity distribution of the secondary electrons was made and it was found that as the primary ion velocity was increased the proportional number of small velocity electrons was decreased.

Recently, Klein[9] obtained secondary emission from nickel due to bombardment by positive ions having a velocity of 50 volts and this emission increased to 22 percent at 380 volts. Klein interpreted certain of his results as indicating a large percentage of positive ion reflection of low speed positive ions.

Townsend[10] in his theory of ionization by collision does not take account of the part which the electrode material may play. On his theory the sparking potential depends only on the properties of the gas. Holst and Osterhius[11] have developed a theory of sparking potential suggested by a series of experiments on the rare gases in which they discovered an important influence of the material of the cathode in the vicinity of the minimum sparking potential.

Reliable data along the line of the present experiment would aid greatly in deciding between the above theories of the sparking potential of a gas.

Description of Apparatus and Method

Fig. 1 shows the type of apparatus used in this experiment. The filament *F*, a platinum strip coated with the iron catalyst source dis-

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[4] Campbell, Phil. Mag. **22,** 276 (1911); **23,** 46 (1912).

[5] Bumstead, Am. Journ. of Sci. **36,** 91–108 (1913).

[6] McLennan and Found, Phil. Mag. **30,** 491 (1915).

[7] Cheney, Phys. Rev. **10,** 335 (1917).

[8] Hahn, Zeits. f. Physik. **14,** 368 (1923).

[9] Klein, Phys. Rev. **26,** 800 (1925).

[10] Townsend, Electricity in Gases, 428 (1915).

[11] Holst and Osterhius, Comptes Rendus **175,** 577 (1922).

covered by Kunsman,[12] emitted a beam of potassium ions when heated to a dull red heat. That the ions emitted from this source were singly charged potassium ions was shown by work done by Barton, Harnwell and Kunsman[13] in this laboratory by the mass spectrograph method.

The ions were accelerated through the system of slits in the molybdenum cylinder *B*, through the hole in the shield *C*, and were collected in the long Faraday cylinder *D*. The experimental tube is drawn to scale, the line in the upper left-hand corner of the figure representing a length of 10 cm. The slits in the cylinders were of such dimensions as to give a well defined beam of ions. The target *T* which was welded to the molybdenum rod *E* and pivoted at *O* could be interposed exactly at the mouth of the cylinder *D*, or withdrawn from the opening, by applying a magnetic field to the iron armature *H*. A nickel cylinder *N* in whose head was a pivot carrying the target, could be made to slide on the tungsten rods *M* by a magnetic control. The target could thus be moved back in the tube a few centimeters from the end of *D* so that it could be heated by induced currents from a high frequency a.c. coil wound around the tube. The rods *M* were mounted through a ground glass joint sealed on the outside by De Khotinsky cement. The filament *F* was mounted similarly through another ground glass stopper.

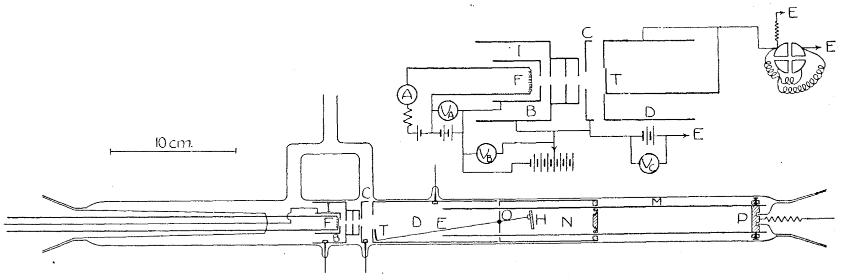

Fig. 1. Diagram of apparatus.

The apparatus was evacuated by means of a mercury diffusion pump backed by a Cenco Hyvac pump. There were two outlets from the tube so that as good a vacuum as possible might be obtained between *B* and *D* and any gas which might come from the filament was thus rapidly pumped out. Before a series of runs the experimental tube was baked in an electrical furnace at about 400°C. Liquid air was used to keep oil and mercury vapor from the apparatus. During a run with the pumps going the pressure was too small to be detected by a McLeod gauge reading 10^{-6} mm of mercury.

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[12] Kunsman, J. of Phys. Chem. **30,** 525–534, April (1926).

[13] Barton, Harnwell and Kunsman, Phys. Rev. **27,** 739 (1926).

The upper right-hand portion of Fig. 1 shows the electrical connections. A constant potential difference V_A of 90 volts supplied by dry cells was applied between the filament F and the iron cylinder I. This cylinder was used to shield the filament magnetically. The accelerating potential V_B was varied from 0 to about 1000 volts. Dry cells supplied this voltage V_B which was measured by a Weston Standard voltmeter having a resistance of one megohm. The currents were measured by the constant deflection method on a Dolazek electrometer with a sensitivity of about 1000 divisions per volt, shunted by India ink resistances. A few turns of fine platinum wire were wrapped around the stem and tube, and connected to earth as guard rings. The whole apparatus was enclosed in an earthed wire cage. With such precautions the possibility of surface leakage of electricity from the outside or electrostatic disturbance was reduced to a minimum.

The difference in the electrometer current in the two positions of the target gave a measure of the secondary emission.

Let I_+ represent the primary positive ion current, I_- the secondary electron current, and I_r the current due to reflected positive ions.

If, when the target is withdrawn, the total current measured is I_1, and when the target is exposed to bombardment the current measured is I_2, we have

$$I_1 = I_+ \text{ and } I_2 = I_+ + I_- - I_r,$$

whence

$$\frac{I_1}{I_2} = \frac{I_+}{I_+ + I_- - I_r},$$

therefore

$$\frac{I_2 - I_1}{I_1} = \frac{I_- - I_r}{I_+}$$

is the ratio of the secondary emission to the primary positive ion current.

Now if a transverse magnetic field be set up which causes the emitted electrons to be curved back upon the target but which is not large enough to affect the positive ions, then

$$\frac{I_1^H - I_2^H}{I_1^H} = \frac{I_r}{I_+}$$

is the ratio of the positive ions reflected to the primary positive ion current, I_1^H and I_2^H being the current measured with the magnetic field applied when the target is back and forward respectively.

An idea of the magnitude of the magnetic field necessary to bend the electrons without affecting the positive ions can be obtained from a formula given by J. J. Thomson[14] for determining e/m when using a magnetic field to stop ions passing between parallel plates; namely, $e/m = 2V/(Hd)^2$ where e/m is the ratio of the charge to the mass of the ion, V the potential difference between the plates, H the magnetic field, and d the distance between the plates.

RESULTS

(a) *Secondary emission.* In Fig. 2 experimental curves are given in which $(I_2 - I_1)/I_1$ expressed in percent is plotted as ordinate and V the accelerating potential of the positive ions is plotted as abscissa. Curve B is a typical curve for a molybdenum target which had been baked *in vacuo* at about 1000°C, and then exposed to air before final evacuation of the apparatus. Curve B_1 shows the results obtained using the same target after it had been baked *in vacuo* in the experimental tube by induced currents. Curve A shows the results for a molybdenum target which had been baked as before, exposed to a gas flame and then mounted in the tube. Curve A_1 gives the percentage secondary emission for various speeds of the bombarding positive ions, after the target had been baked in the apparatus. It will be noted that the emission depends somewhat on previous treatment of the target.

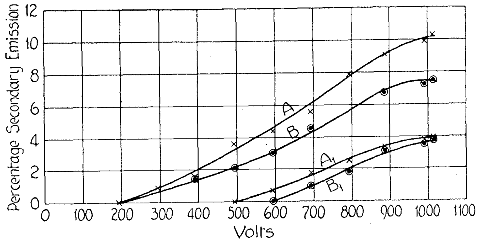

Fig. 2. Percentage of secondary emission as a function of velocity of positive ions.

Fig. 3 shows the emission from three metals, molybdenum, nickel, and aluminum, which had been baked in the experimental tube. Curves are not given to indicate the amount of emission from aluminum and nickel before baking in the apparatus. It will suffice to say that from aluminum an emission of 15 percent to 20 percent was obtained due to the bombardment of 1000 volt positive ions, and in the case of nickel an emission of about 7 percent was measured due to ions of the above speed.

(b) *Positive ion reflection.* In experiments on positive ion reflection a transverse magnetic field was applied at the target. In the case of molybdenum positive ion reflection did not exceed 2 percent for the highest

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[14] Thomson, Conduction of Electricity Through Gases, Second Edition, p. 219.

speeds of primary ions used. In working with nickel it was discovered that the magnetic field could not be utilized to separate the effect of positive ion reflection from electron emission owing to the magnetic property of the nickel which weakened the field in the region of emission. However, since it was found that the electrons emitted from nickel had low speeds, nearly all being stopped by a fraction of a volt and none having a speed greater than 3 volts, a retarding field of 3 volts for electrons was applied between *C* and *D* (Fig. 1) and it was then discovered there was not more than 2 percent reflection of positive ions. In the case of aluminum there was no evidence of positive ion reflection.

If a field of 45 volts was applied to retard positive ions between *C* and *D* (Fig. 1), the low speed ions 0 to 2 volts were affected by the field and cases were obtained in which 50 percent fewer ions reached the cylinder *D* when the target was forward than in the case of the target being back. This phenomenon disappeared when the field between *D* and *C* was made small. It is quite evident, therefore, that this is not a phenomenon of reflection of low speed positive ions but an effect due to deflection of primary ions by the field. These observations at large retarding fields were exactly similar to those reported by Klein[9] and interpreted by him as indicating positive ion reflection. The present observations show that positive ion reflection is certainly less than 2 percent, and may be zero.

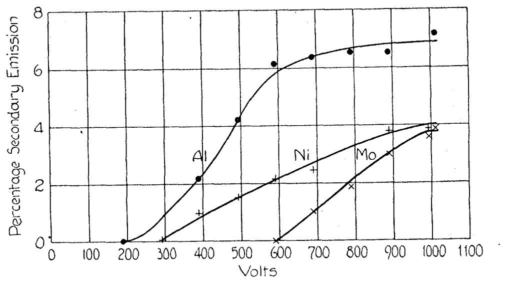

Fig. 3. Percentage of secondary emission as a function of velocity of positive ions.

(c) *Velocity of the emitted electrons.* It was found that the electrons emitted from the three metals were of low speed. In the experiments performed practically all could be stopped by retarding fields of a fraction of a volt.

Table I shows the fraction of emitted electrons having speeds less than a certain value for various speeds of bombarding positive ion. The data given in Table I were obtained from a nickel target.

TABLE I

V_Bv	$(f)^*$ 0.1v	(f) 0.2v	(f) 0.3v	(f) 0.5v	(f) 1.0v	(f) 2.0v
400	.5	1	1	1	1	1
500	.7	1	1	1	1	1
600	.7	.9	1	1	1	1
700	.7	.85	.93	1	1	1
900	.58	.58	.61	.79	.84	.88

*f (v) means the fraction having speeds less than v volts.

The above table indicates that the velocity distribution among the secondary electrons increases with the speed of the bombarding positive ion.

DISCUSSION OF RESULTS

From the curves in Fig. 1 it will be seen that the emission from metallic surfaces due to positive ion bombardment depends on the treatment of the surface. Doubtless much which is measured as electron emission from metals is really emission from layers of gas absorbed on the surface. One feature of the experiment was the baking of the target in the experimental tube by induced currents.

It should be noted as shown in Fig. 3 that secondary emission sets in for aluminum at a lower voltage of bombarding ion than for nickel, and emission from nickel at a lower voltage than from molybdenum. This may be due to aluminum having a lower work function than nickel and nickel having a lower work function than molybdenum.[15] Whether or not this is the explanation will become clearer after more metals have been studied. Perhaps results obtained from aluminum are not comparable with those from nickel and molybdenum as difficulty was encountered in getting the aluminum target baked by induced currents.

This work is being continued with other metals and other kinds of positive ions, in an endeavor to throw more light on the phenomenon of secondary emission from metals. A steady source[12] of positive ions of different kinds being available makes experimentation in this field easier.

In conclusion, the writer wishes to express his thanks to Professor K. T. Compton, at whose suggestion the problem was undertaken, for his kindly interest and helpful counsel during the progress of the work, to Mr. C. C. Van Voorhis who helped in the construction of the apparatus used, and to Mr. Leigh Harris who did the glass work on the experimental tube.

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[15] Richardson, Emission of Electricity from Hot Bodies, pp. 81–82.