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SECONDARY EMISSION FROM Mo DUE TO BOMBARDMENT BY HIGH SPEED POSITIVE IONS OF THE ALKALI METALS

By W. J. Jackson

Abstract

Work has been extended to measurements on secondary emission from Mo due to the bombardment of positive ions of Na^+, Rb^+ and Cs^+ following the method used for K^+ and described in detail in a previous paper. Confirmatory evidence is obtained that heat treatment in general reduced the secondary emission. With degassed targets the following results were obtained: Na^+ ions showed a positive ion reflection of 3 percent or 4 percent independent of the speed of the impacting ion and electron emission of about 2 percent at 1000 volts. Experiments with Rb^+ indicated a reflection of positive ions of less than 2 percent and no electron emission within the experimental error. Cs^+ gave a secondary emission of about 9 percent at 1000 volts. It is suggested that the relatively large secondary emission from an untreated target as compared with a well degassed metal is possibly due to the minimum distance of the electron from the metal surface being greater in the former than in the latter case; also if secondary emission is due to local high temperatures arising from positive ion bombardment there would be more rapid dissipation of energy by the target surface than by the gas molecules.

Introduction

In a previous paper[1] the writer described a method for measuring secondary emission from metals due to the bombardment of K^+ ions. The method was designed to separate the phenomenon of positive ion reflection from electron emission. A special feature of the apparatus was the arrangement whereby the target could be drawn back in the tube and heated by induced currents from a high frequency a.c. coil wound around the tube. The results of the above mentioned work showed that the secondary emission depended upon the metal used as a target and also very considerably on the condition of its surface. Since steady sources[2] of positive ions of different kinds were available it was decided to extend this work to the ions of the other alkali earth metals, Na^+, Rb^+ and Cs^+ ions, in an endeavor to find how the emission depends on the nature of the ions used.

Work by Cheney[3] showed that the electron emission from a metallic surface was a function of the bombarding ion. In the case of aluminum and platinum targets the emission due to potassium ions of a given energy lay between that due to rubidium and lithium ions of the same energy, the latter giving the greatest emission of the three kinds of ions used. The writer obtained smaller values for emission from aluminum using potassium ions and a degassed target than were found by the above investigator.

It was pointed out in the previous paper that in order to decide between present theories of sparking potential of a gas and also to construct theories

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[1] Jackson, Phys. Rev. **28**, 524 (1926).

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

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

of other phenomena of discharge in gases, such as normal cathode fall of potential and abnormal fall of potential, reliable data along the line of the present work should be obtained. The theory of sparking potential of a gas by Holst and Osterhuis[4] requires the sparking potential to depend not only on the cathode material but also on the nature of the positive ions striking the cathode. If this theory be correct, one might expect to find a secondary emission from a given metallic surface characteristic of the bombarding ion.

Apparatus and Method

The apparatus, Fig. 1, and the experimental procedure in the work of this paper were exactly similar to those described in the original paper.

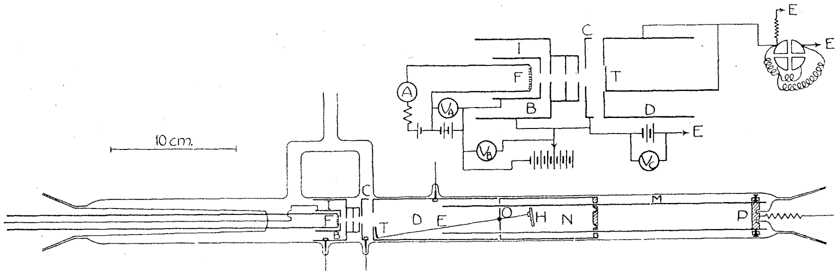

Fig. 1. Diagram of apparatus.

One thing should be mentioned which was not previously noted. It was necessary to carry out experiments on secondary emission and positive ion reflection separately owing to the fact that observations of secondary emission differed according to whether the magnet used for bending the emitted electrons was placed on or was removed from the experimental apparatus. The secondary emission was less in the former case.

Apparently there was sufficient residual magnetism in the pole pieces of the magnet appreciably to bend the paths of the lowest speed electrons. To eliminate all magnetic effects an iron shield was placed around the tube when experiments on secondary emission were made and removed when the magnet was set up for experiments on positive ion reflection.

The positive ions used in the experiments were obtained from the iron catalyst source discovered by Kunsman.[2] The ions emitted from the separate catalysts containing respectively Na, K, Rb and Cs were shown by Barton, Harnwell and Kunsman[5] to be only the corresponding singly charged positive ions, except for a trace of K as an impurity in relatively small amount. A Mo target was used throughout the experiments.

Sodium. The result of the original experiments, namely, that the emission was greatly reduced by baking the target in the experimental tube was confirmed by the experiments using Na^+ ions and also Rb^+ and Cs^+ ions. It should be noted in the case of a Mo target bombarded by K^+ ions that there

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[4] Holst and Osterhuis, Comptes Rendus **175**, 577 (1922); Phil. Mag. **46**, 1117 (1923).

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

was a secondary emission of about 3.8% due to 1000 volt ions and a reflection of positive ions of less than 2%. This would make the electron emission less than 5.8% at 1000 volts. Using Na^+ ions and a well degassed target values for positive ion reflection were obtained which amounted to about 3% or 4% and did not depend on the velocity of the impacting ion. The experiments with these (Na^+) positive ions were repeated twice at intervals of a month and the results checked well within the experimental error. The experiments on secondary emission indicated small values of electron emission, nothing appreciable below 600 volts, and even up to 1000 volts the electron emission amounted in some cases to less than 2% and the greatest value obtained in this region was about 2.7%. The experimental error is great in the case of the measurements taken where the emission is small for the results come from the difference of two experimental readings. It should also be noted that when observations on positive ion reflection were taken with an unbaked target a reflection of less than 2% was obtained.

Rubidium. Table I shows a typical set of data for secondary emission from an unbaked Mo target due to Rb^+ ion bombardment. *V* is the energy in volts of the positive ions.

TABLE I

Secondary emission from an unbaked Mo target due to Rb^+ ion bombardment.

V	Percentage Secondary Emission	*V*	Percentage Secondary Emission
137	0.0	692	3.9
342	0.4	792	7.8
492	1.5	892	7.8
592	2.5	1072	13.1

On baking the target the emission dropped to an unmeasurably small value and there was less than 2% positive ion reflection, or possibly no reflection, for the experimental error was such that the measurements cannot be relied upon for these small percentage differences.

It is important in measurements on secondary emission not to have large fields near the target which may distort the primary beam giving effects which may wrongly be interpreted as positive ion reflection or electron emission. A case of this kind was cited in the first paper.[6] Curve II of Fig. 2 below shows a typical curve for emission due to Rb^+ ions and an unbaked Mo target using the usual electrical connection as shown in Fig. 1. Curve I shows the measurements of secondary emission when the iron cylinder and *B* were kept at the same potential and the accelerating field for positive ions was applied between *B* and *C*; as before *C* was kept 2 volts positive with respect to earth.

As a possible explanation of this phenomenon it is suggested that this increased secondary emission may be due to the effect of the irregular field on the positive ions causing them to hit the target at angles other than perpendicular incidence. In the experimental arrangement used throughout

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[6] Jackson, Phys. Rev. **28**, 529 (1926).

the work as shown in Fig. 1, it is more probable that the positive ion beam hits the target at right angles to the surface than in the latter arrangement. Preliminary experiments indicate that emission depends on the orientation of the target with respect to the primary beam, but the results are not definite enough to give decided support to the above suggestion.

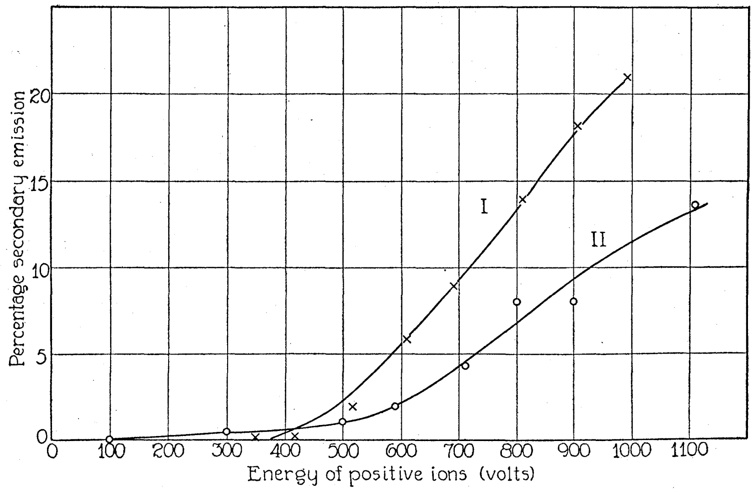

Fig. 2. Percentage of secondary emission as a function of velocity of positive ions.

It was found that the electrons emitted are of low speed.[7] Table II shows the velocity distribution among the secondary electrons for the case of Rb^+ ions bombarding a Mo target.

TABLE II

V	(f) 0.1 v	(f) 0.2 v	(f) 0.3 v	(f) 0.5 v	(f) 1.0 v	(f) 2.0 v
500	0.38	0.62	0.81	1.0	1.0	1.0
600	.42	.55	.66	.66	.79	1.0
700	.51	.58	.66	.71	1.0	1.0
950	.43	.53	.58	.68	.68	.93

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

The table indicates that the average velocity distribution among the secondary electrons increases with the speed of the impinging ion.

Caesium. In Fig. 3, curve A shows the secondary emission (electron emission plus positive ion reflection) from a baked Mo target when bombarded by Cs^+ ions, as compared with similar emission due to K^+ ions shown in curve B.

The writer found it a little difficult to interpret the results on caesium as regards separating positive ion reflection and electron emission. The readings obtained when the magnetic field was applied direct and reversed

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[7] Baerwald, Ann. d. Physik. **60**, 26 (1919).

were different in the case of readings taken when the target was bombarded. No such difference in readings occurred when the target was withdrawn. However, the evidence indicates that there is little reflection and, if any, that this occurs when the ions have low speeds. Experiments were carried out to see if this effect of the magnetic field was due to the direct and reverse field affecting the reflected positives of low speed. No evidence was obtained to support this hypothesis. The differences occur where electron emission sets in and it may be that due to non-symmetry of the apparatus all the electrons were not bent by the field in one direction.

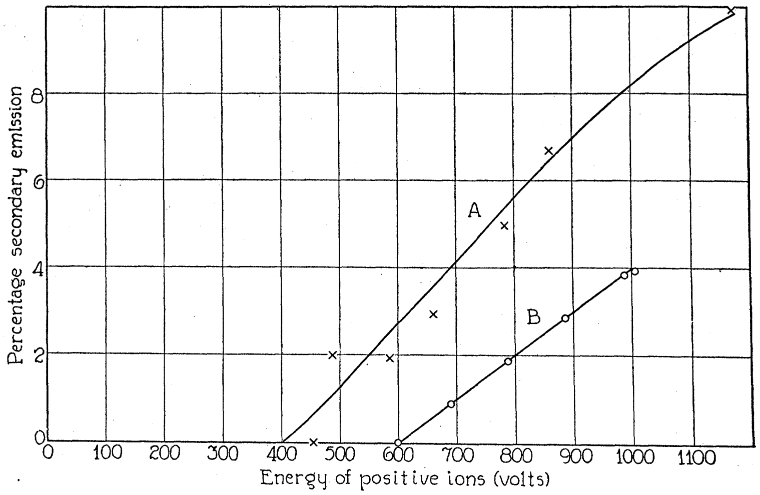

Fig. 3. Percentage of secondary emission as a function of velocity of positive ions.

Discussion of Results

The phenomena presented in this and the former paper have shown conclusively that when the surface of a target is in a condition to emit electrons due to positive ion bombardment the percentage secondary emission is a function of the speed of the impacting ion.

In a paper criticising the theory of sparking based on secondary emission as set forth by Holst and Osterhuis,[4] Townsend[8] rejects all modes of generating ions as contributing to the effect required to explain the disruptive discharge save the method which assumes the extra ionization as due to collisions of the positive ions with the gas molecules. Townsend rejects the notion that the extra ionization is produced by electron emission from the cathode by positive ion impact on the ground that such a process, in order to lead to the right relationships, requires that the number of electrons set free at the cathode should be independent of the velocity with which the positive ions impinge on the cathode. The writer would like to point out that this is not a requirement of the Holst and Osterhuis[4] theory. The theory

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[8] Townsend, Phil. Mag. **45,** 444 (1923).

merely states that there exists a certain probability w, which is a function of the work-function of the metal, that the positive ion moving to the cathode surface before neutralization causes a second electron to escape from the cathode. The condition for the initiation of the spark is that $(2^g-1)w>1$. Below the minimum sparking potential the probability w is such that $(2^g-1)w<1$, and thus no discharge takes place. This would indicate that the positive ions must have a certain minimum velocity before w becomes large enough to produce the discharge.

Taylor,[9] from recent work on sparking potentials in neon-helium gas mixtures using treated cathodes, has suggested that the secondary electrons are given off from the cathode surface by the photo-electric effect of the radiation accompanying the neutralization of the positive ions at the cathode surface. Experiments showing an increase in sparking potential on passing a heavy discharge were explained by assuming the formation of a charged double-layer which inhibited the emission of electrons.

The question arises as to why electrons are more readily liberated from a gas covered surface than from a degassed metal. The explanation for our experiments cannot be as suggested by Taylor to account for his observations. The following is suggested as a possible explanation.

Consider a metal as an infinite plane. When the electron is at a distance r from the surface it may be considered as attracted by an equal mirror image positive charge. The force of attraction[10] is given by $F=e^2/4r^2$. Assuming that the only force on the escaping electron is its mirror image force then the work done in escaping is $e^2/4x_0$ where x_0 is the minimum distance or its equivalent. Perhaps this distance x_0 is less in the case of a gas free surface than when a gas layer is present.

Also if secondary emission is due to local high temperatures arising from positive ion bombardment certainly there would be more rapid dissipation of the energy by the conducting target surface than by the gas molecules which would favor emission from a gas covered surface.

The results of the earlier investigations regarding secondary emission as depending on surface conditions have been confirmed by the experiments described in this paper. It has not been possible to correlate results of emission due to Na^+ K^+ Rb^+ and Cs^+ ions using an untreated target with the atomic weight, or to obtain a correlation in the case of a degassed metal; surface condition in the former case played a decisive rôle.

My thanks are due to Professor K. T. Compton, who suggested this investigation, and has shown continued interest and has given much helpful advice throughout the course of the research.

Palmer Physical Laboratory,
Princeton, New Jersey,
June 17, 1927.

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[9] Taylor, Phil. Mag. **3,** 753 (1927).

[10] Schottky, Phys. Zeits. **15,** 872 (1914).