

THE SECONDARY EMISSION FROM A NICKEL SURFACE  
DUE TO SLOW POSITIVE ION BOMBARDMENT

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## ABSTRACT

The apparatus was arranged so that positive ions from a heated Mo strip coated with aluminum phosphate, were accelerated radially through slots in shields *A* and *B*, and a wider slot in an electrode *C* to the target *T*, from which the secondary emission to the electrode *C* was measured. The parts *A*, *B*, *C* and *T* were all concentric nickel cylinders, symmetrically placed about the emitter. If the potential of the emitter is made zero and the accelerating potential  $V_1$ , when the collector is at zero potential only reflected positives are collected. As the potential is increased, secondaries also reach it, the net negative charge increasing until a saturating potential  $2V_1$  is reached, when all negatives and no positives are collected. The percentage saturated *secondary electron emission* was found to increase approximately as the square of the primary ion energy, reaching 22 percent of the primary ion current, for primary ions of energies corresponding to 380 volts. The curves show that large numbers of *reflected positive ions* have energies between zero and two volts, and there is also a group of reflected positive ions with energies approximately 0.9 of the primary energy.

THE problem of the secondary emission from metallic surfaces due to positive ion bombardment has been attacked by several workers. Among others Fuchtbauer,<sup>1</sup> Cheney,<sup>2</sup> Baerwald,<sup>3</sup> Hahn,<sup>4</sup> and Baderau<sup>5</sup> have made important contributions.

The apparatus used in this work consisted of a number of coaxial nickel cylinders arranged symmetrically around a central molybdenum positive ion emitter. The emitter consisted of a strip of molybdenum 0.13 mm thick, 2.5 mm wide, and 12 mm long; this strip was bent into an open circular band, and heated by passing an electric current through it. The emitter was activated by covering it with a thick layer of  $\text{AlPO}_4$ . The innermost cylinder designated in Fig. 1 as *A*, was 10 cm long and 3 cm in diameter, and has a slot 1.5 mm wide cut around its center, except in three places where legs were left to hold the two parts of the cylinder together. The ends of the tube were closed by means of nickel caps. The next cylinder *B* is 5 cm long and 3.5 cm in diameter. It has a slot around its center aligned with the one in *A*, but three mm wide. The two collect-

<sup>1</sup> Fuchtbauer, Phys. Zeits. **7**, 153 and 748 (1906); Ann. der Phys. **23**, 308 (1907).

<sup>2</sup> Cheney, Phys. Rev. **10**, 335 (1917).

<sup>3</sup> Baerwald, Ann. der Phys. **41**, 643 (1913); **60**, 1 (1919); **65**, 167 (1921).

<sup>4</sup> Hahn, Zeits. f. Phys. **14**, 335 (1923).

<sup>5</sup> Baderau, Phys. Zeits. **25**, 137 (1924).

ing cylinders  $C'$  and  $C''$  are each 4 cm in diameter and 2.5 cm long. The distance between them is 13 mm. The fourth cylinder  $T$  is the target and is 5 cm in diameter and 5 cm long. This cylinder is pierced with an observation hole approximately 8 mm in diameter. This cylinder has attached to it a constantan-tungsten thermocouple.

The apparatus was inclosed in a Pyrex glass bulb and evacuated by means of a two stage mercury diffusion pump backed by a Cenco Hyvac pump. Liquid air was kept on the apparatus during observations and the pressure was measured by means of a McLeod gauge. Before taking any observations the target was always glowed out at  $1000^{\circ}\text{C}$  for three or four minutes by means of induced currents.

The electrical connections are shown in Fig. 2. The emitter  $E$  was heated by means of a large six volt storage battery. The cylinder  $B$  is grounded and the emitter is made positive; the cylinder  $A$  is made less positive than  $E$  so that part of the potential drop occurs between  $E$  and  $A$  and the remainder between  $A$  and  $B$ . The target  $T$  is connected to the cylinder  $B$  through the galvanometer  $G_1$ . The two collecting cylinders  $C'$  and  $C''$  are connected together and then through the galvanometer  $G_2$  and the variable potential  $V_3$  to the

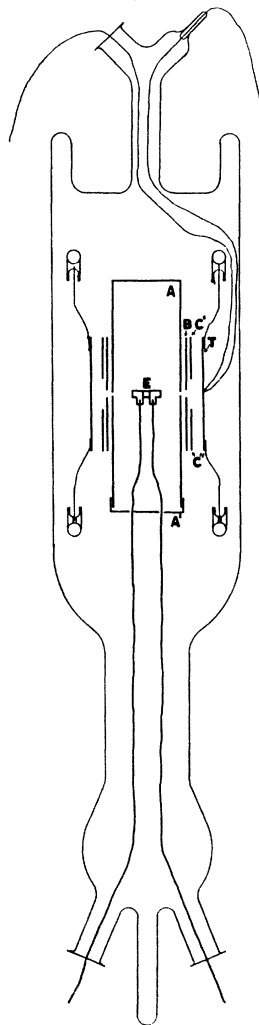


Fig. 1. Diagram of the apparatus.

target  $T$ . Thus a positive ion on evaporating from  $E$  is accelerated through the slots in  $A$  and  $B$  and then impacts against  $T$ ; then by means of the variable potential  $V_3$  a saturation curve of the emission from  $T$  due to the impact of the positive ions upon it can be obtained.

The galvanometer  $G_1$  (Leeds and Northrup type R) has a sensitivity of the order of 1800 megohms; galvanometer  $G_2$  (Leeds and Northrup

type HS) has a sensitivity of the order of 16,000 megohms. It will be noticed that  $G_1$  reads all of the positive ion current that arrives at the target or collectors, while  $G_2$  reads only the current between the collectors and the target. Consequently the reading of  $G_2$  gives for any particular voltage  $V_3$  the sum of the secondary electron emission and the secondary or reflected positive ion emission. By dividing the reading of  $G_2$  by the reading of  $G_1$  the ratio of the secondary current to the primary current is obtained.

*Method of procedure.* In taking a series of observations the target is first glowed out at  $1000^\circ\text{C}$  for a few minutes and the emitter heating current is turned on. The apparatus is then left for about 15 minutes

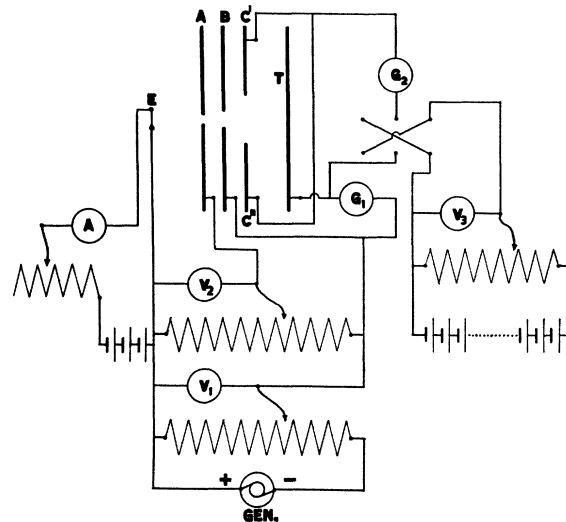


Fig. 2. Diagram of electrical connections.

until the temperature conditions become stable as shown by the thermojunction. Then the fields are applied so that the positive ions are accelerated from the emitter through the slots in  $A$  and  $B$  against the target  $T$ . Observations are started by making the collectors  $C'$  and  $C''$  negative with a potential equal to that of the positive ions incident on the target. A reading of  $G_1$  and  $G_2$  is then taken, after which the potential of the collectors is decreased somewhat towards zero, and another reading is taken. This is repeated until the potential reaches zero, and then the potential is increased in the positive direction by small increments until it reaches a positive voltage equal to twice the voltage of the incident positive ions. If the ratio of the readings of  $G_2$  to  $G_1$  is plotted against the potential of the collectors, a saturation curve is

obtained for the current between the collectors and the target. The curves obtained in this way for various voltages of positive ions are shown in Figs. 3, 4, and 5. During observations the vacuum was always

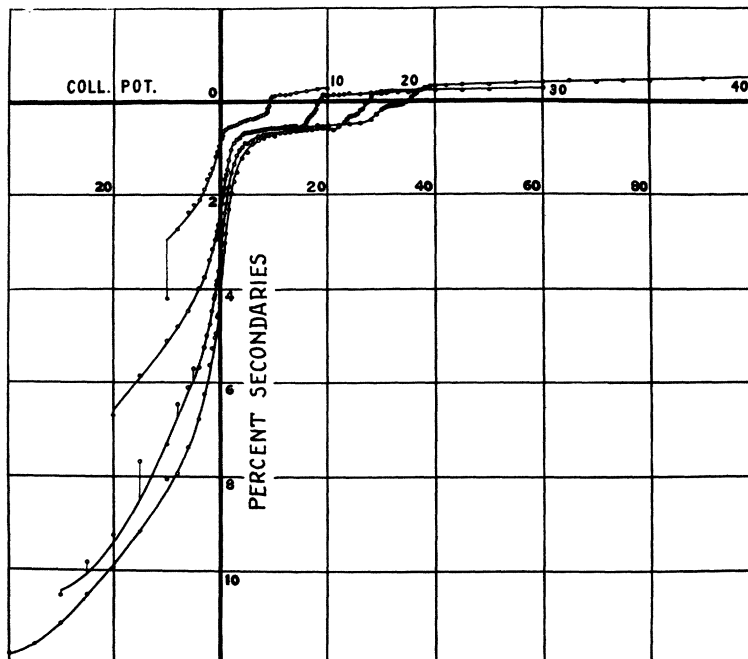


Fig. 3. Curves for accelerating potentials of 10, 20, 30 and 40 volts.

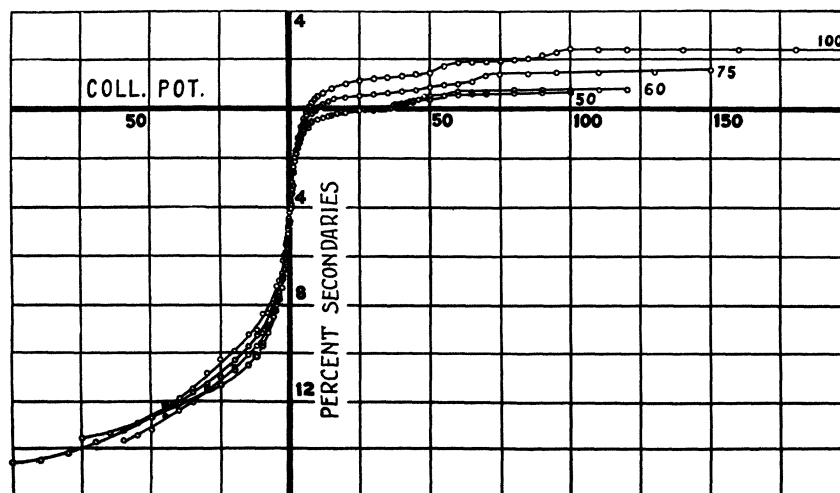


Fig. 4. Curves for accelerating potentials of 50, 60, 75 and 100 volts.

less than  $10^{-5}$  mm of Hg. The temperature of the target was always between  $160^{\circ}\text{C}$  and  $180^{\circ}\text{C}$ .

The positive ions used were obtained from hot  $\text{AlPO}_4$ , and, according to Dempster,<sup>6</sup> are ions of sodium and potassium. The writer has had no opportunity to determine the constitution of the ions used, but he hopes to do so in the immediate future.

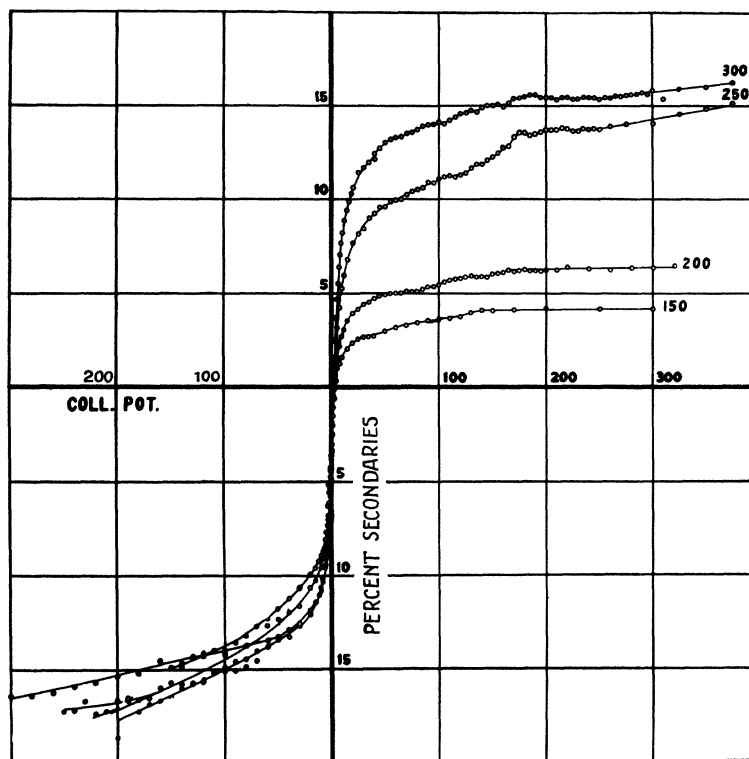


Fig. 5. Curves for accelerating potentials of 150, 200, 250 and 300 volts.

*Discussion of curves.* The saturation curves shown in Figs. 3, 4, and 5 are all plotted with the ordinates representing the percentage ratio of the secondary to the primary current. The abscissas represent the collecting potential, and the numbers at the end of the curves show the value of the primary ion energy for that particular curve. In the plots the ordinates above the axis represent secondary electron emission, those below represent reflected or secondary positive ions; the abscissas to the right represent positive collecting potentials, those to the left negative. It will be noticed that the points to the left of the  $y$ -axis are rather

<sup>6</sup> Dempster, Phys. Rev. **11**, 320 (1922).

scattered and do not lie on a smooth curve as do the points to the right of the  $y$ -axis. This condition is due to the pulling of the ions out of the primary beam by the potential of the collector. As the negative collecting potential comes nearer to that of the primary beam the points scatter more and more. It is evident that curves to the left of the axis are practically identical for all of the different voltages, being simply traced further and further to the left as the voltage of the primary ions increases. There could be no object in increasing the negative potential on the collector to more than the accelerating potential, as then the collector would simply gather in the ions from the primary beam. Also it will be seen that all of the curves have strong points of inflection in the vicinity of zero volts. This large change in the value of the ordinate must mean that there are large quantities of reflected positive ions with energies in the neighborhood of zero volts, as the change is far greater than the total electron saturation current could possibly cause. After this the curves flatten out, pass through one or more new breaks, and finally reach a satisfactory saturation value when the collecting potential has the correct value. The fact that for low accelerating voltages (Fig. 3) the curves do not cross the axis until they are practically at the saturation voltage means that there are large numbers of positive ions reflected with high velocities. There seems to be one group of these reflected positive ions whose energy is about 0.9 that of the incident beam. Other groups of ions are reflected with different energies. This phenomenon serves to mask the emission of the secondary electrons so that only the curves where the energy of the incident beam is high becomes negative when the collecting potential is small.

After it was discovered that the curves all reached a saturation value when the collecting potential was higher than the primary ion potential, a curve was taken by varying the accelerating potential and maintaining the collecting potential always twenty-five percent greater. This curve (Fig. 6) shows the variation of the total secondary current with the positive ion voltage. It will be noticed that the secondary electron current is less than one percent for values below 50 volts. It increases rapidly with the primary voltage reaching a value of 22 percent at 380 volts.

There are a great many other things to be done in the future on this problem. It is proposed to study other target surfaces, to use other kinds of positive ions, and also higher voltages. For the different kinds of positive ions, hydrogen together with the series of alkali metals would be most satisfactory. Ionized hydrogen would give as a bombarding particle a proton which is the smallest known particle. The series of the

alkali metals would give as ions a series with complete K, L, M, N, and O shells. This will be very desirable, as with them the second ionizing potential will be very high, and consequently the probability that an ion will be doubly ionized is very remote. In order to determine the kind of ions that are given off by the emitter it will be necessary to use a mass spectrograph.

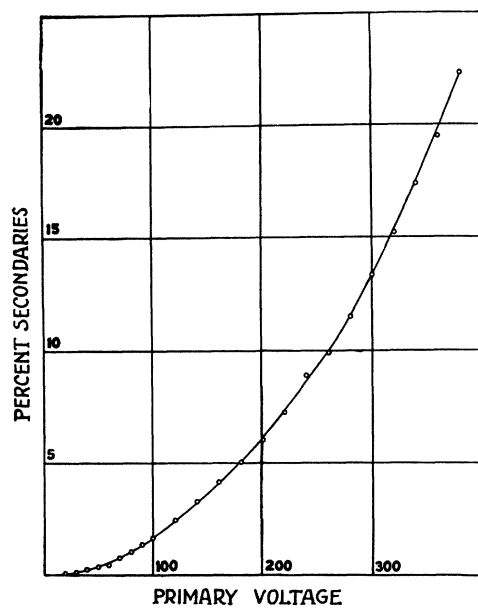


Fig. 6. Dependence of total secondary current on primary voltage.

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